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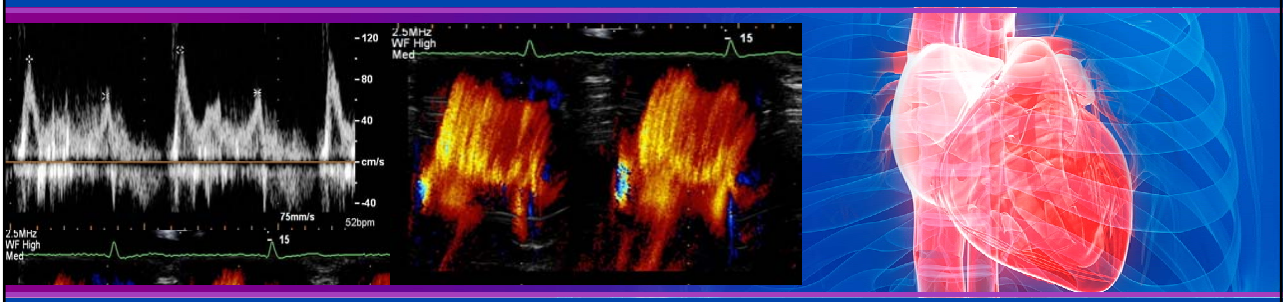
Assessment of Diastolic Function

Challenging, but Can be Simple

ASE Echo Board Review Course

May 8th, 2018



Jae K. Oh, MD

Samsung Professor of CV Diseases

Learning Objectives for Diastology
After this talk, you will be able to

- Understand physiology and hemodynamics of diastole
- Know correlation between Echo diastolic parameters and underlying hemodynamics
- Classify and grade diastolic function
- Estimate filling pressure reliably in most patients at rest and with exercise
- Understand pitfalls of Echo diastolic function assessment

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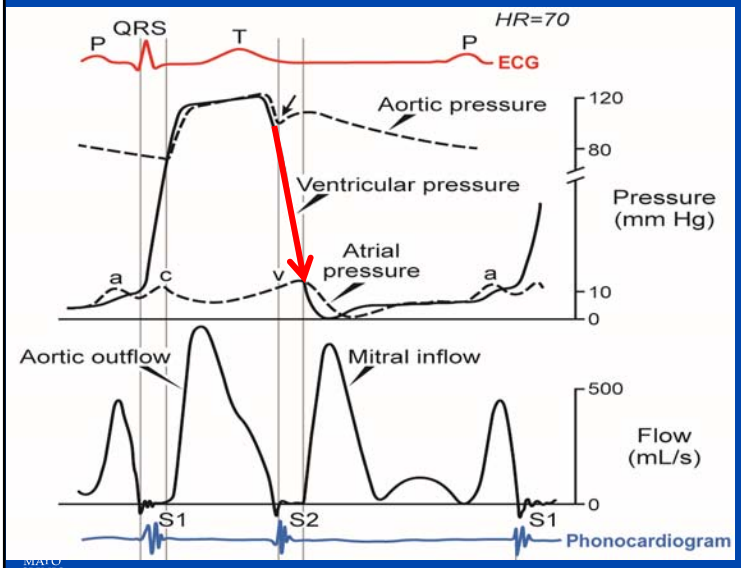
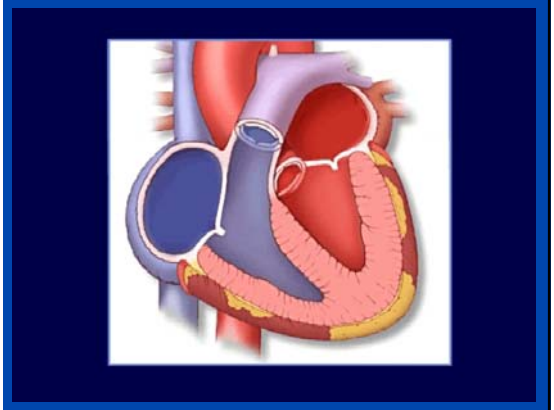
Diastolic Filling with Relaxation





A Clinical Study of Left Ventricular Relaxation

YUZO HIROTA, M.D.

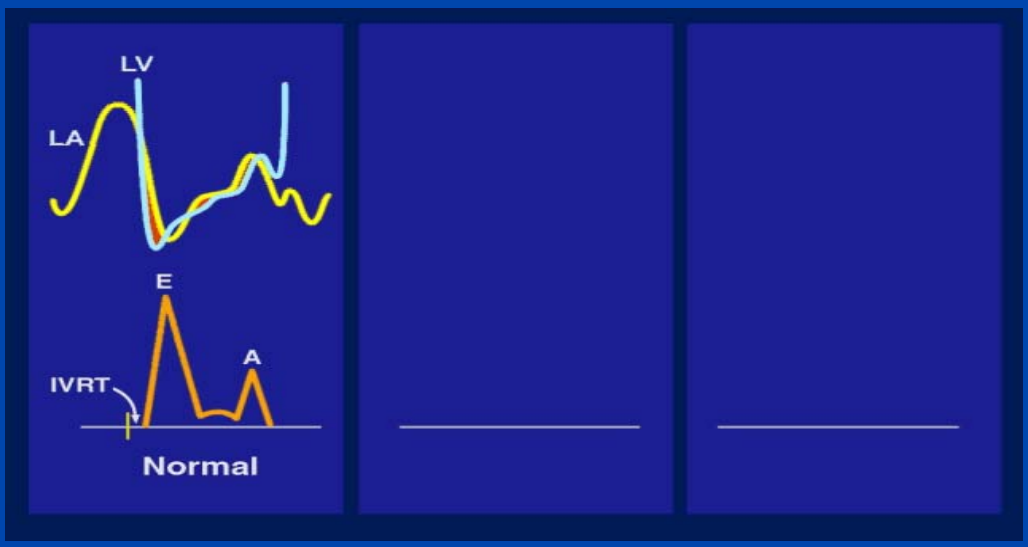
Circulation 1980

SUMMARY Left ventricular (LV) relaxation was studied in patients with hypertrophic cardiomyopathy (HCM, n = 18), congestive cardiomyopathy (CCM, n = 11), hypertensive heart disease (HHD, n = 8), coronary artery disease (CAD) without left ventricular (LV) asynergy (n = 9) and with LV asynergy (n = 17), mitral stenosis (MS, n = 16), and mitral regurgitation (MR, n = 8). The time constant T and peak negative dP/dt were used as indexes of LV relaxation, and 18 normal subjects served as controls.

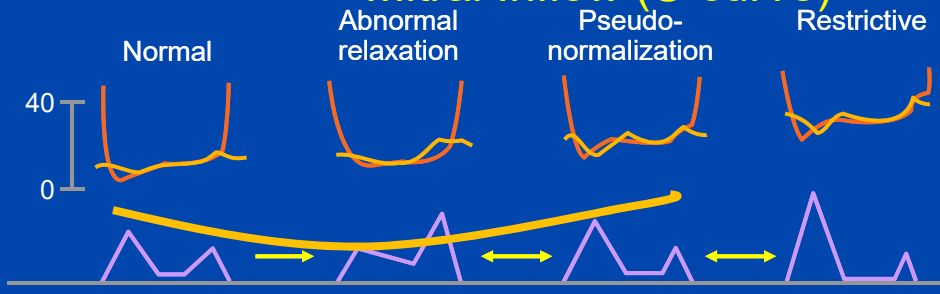
The time constant T was higher in elderly patients among normal controls ($r = 0.652$, $p < 0.01$), which suggests that prolongation of relaxation is a phenomenon of aging. The normal value of the time constant T was 33 ± 8 msec (mean ± SD), and that of peak negative dp/dt was 1864 ± 390 mm Hg/sec. The time constant T was significantly higher in HCM (64 ± 20 msec), CCM (56 ± 14 msec), CAD without asynergy (53 ± 16 msec), CAD with asynergy (57 ± 13 msec) and MS (47 ± 12 msec). Peak negative dP/dt was significantly lower in HCM (998 ± 303 mm Hg/sec), CCM (1060 ± 334 mm Hg/sec), CAD with asynergy (1370 ± 299 mm Hg/sec), MS (1367 ± 313 mm Hg/sec) and MR (1139 ± 305 mm Hg/sec)

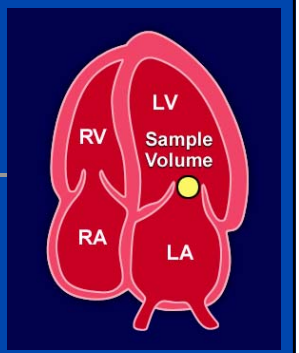
Myocardial relaxation is one of the earliest manifestations of mechanical dysfunction of the human LV. The time constant tau (T) is higher in the elderly and patients with HCM, CAD, and cardiomyopathies.

Echo evaluation of diastolic function
Trans-mitral inflow velocity



Diastolic Function Grading
Mitral Inflow (U curve)

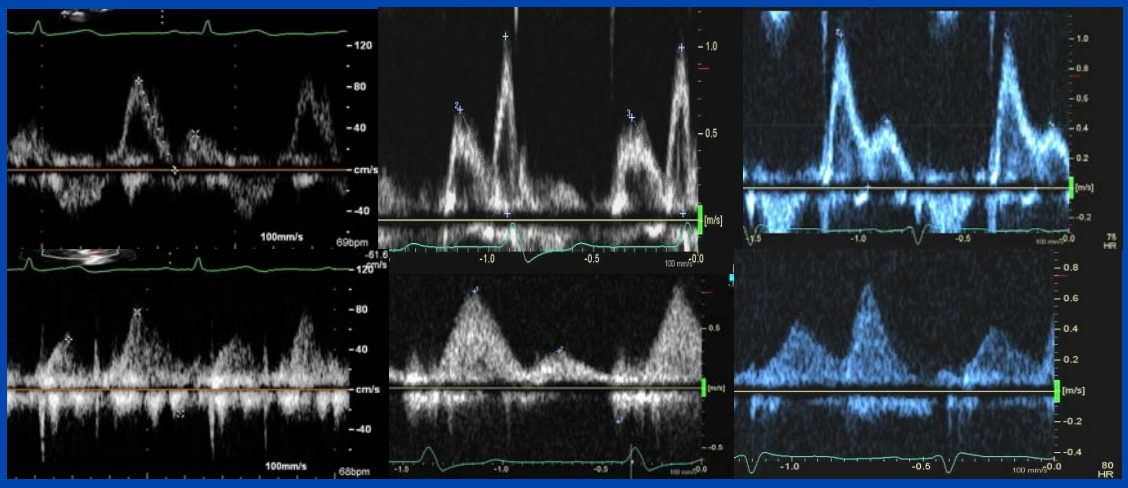




LAP	NL (< 15)	Normal	↑ ↑	↑ ↑ ↑
TAU	NL (< 45)	↑	↑	↑ ↑
Grade		1	2	3

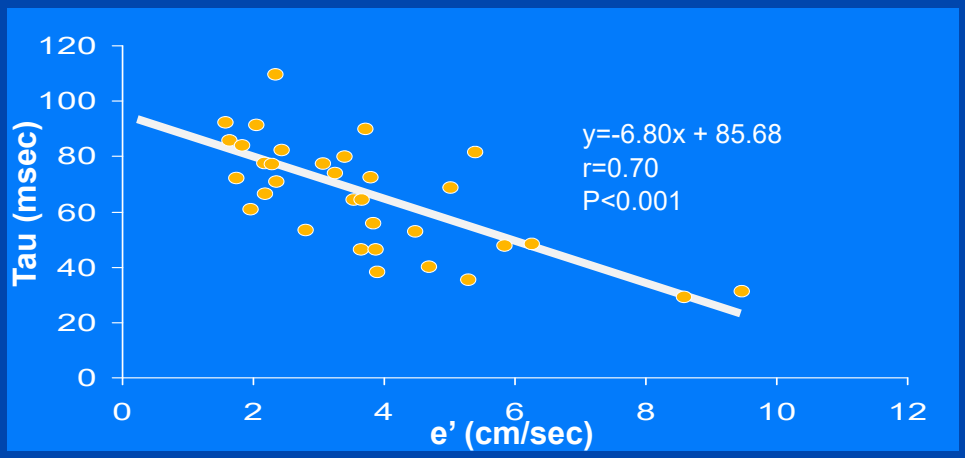
Concept from Appleton and Hatle, 1985

Mitral Inflow and Pulmonary Vein Flow
Diastolic Function Assessment



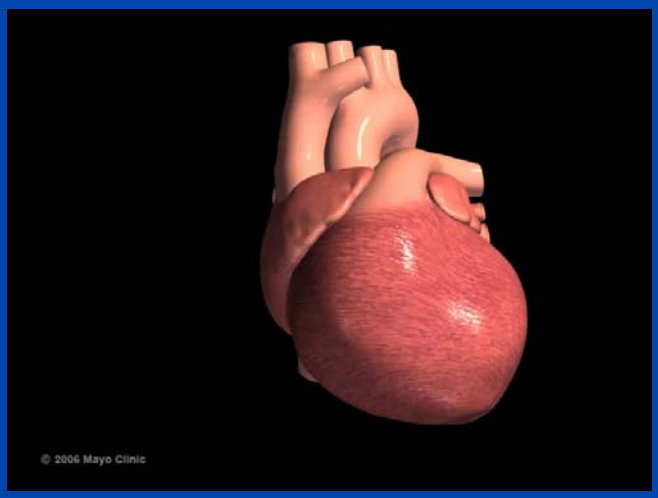
Grade 1 Grade 2 Grade 3

LV Relaxation by Cath and Echo
τ (tau) vs e' (mitral annulus velocity)



Firstenberg et al: J Appl Physiol 90:299, 2001, Nagueh et al: JACC 1997
Oki et al: AJC 1997 , Sohn et al:JACC 1997, Ommen et al: Circ 2000 Opdahl et al: Circulation 119:2578, 2009, and more

Assessment of LV Relaxation by Echo
e' velocity reflects LV relaxation



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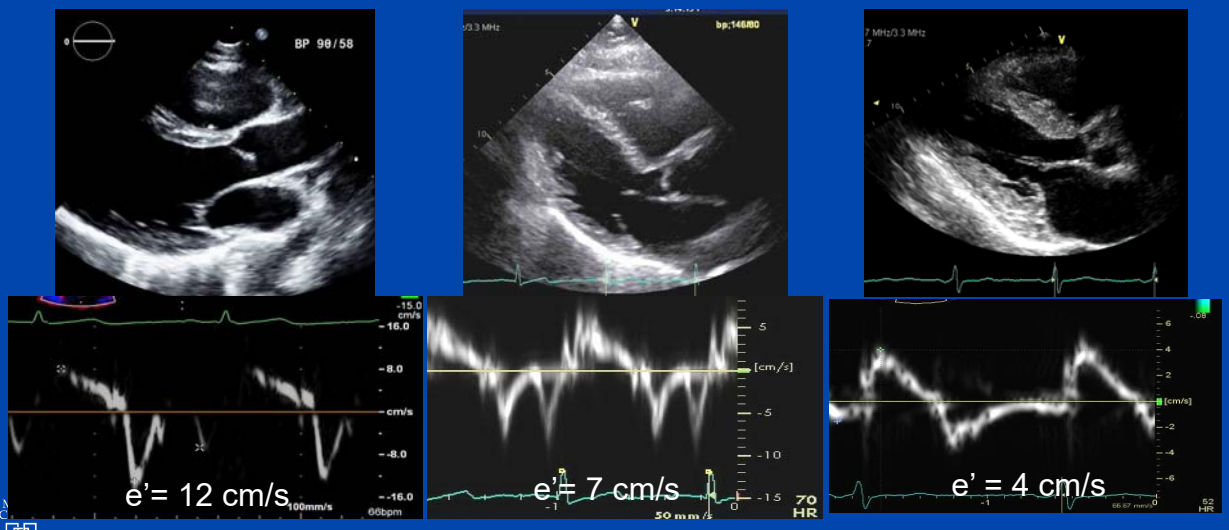
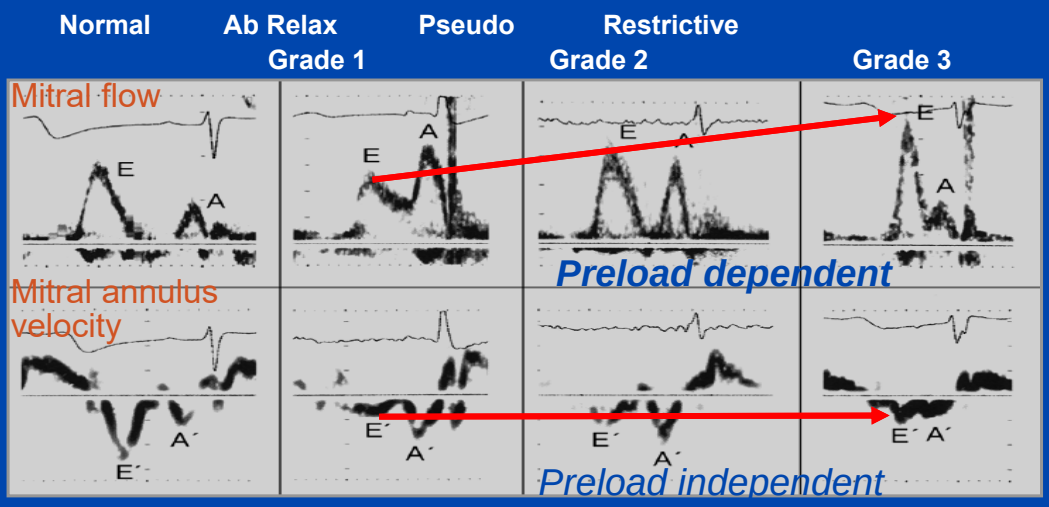
Myocardial Relaxation is the Key for Diastole

Myocardial Relaxation (e')



Evaluation of Diastolic Function

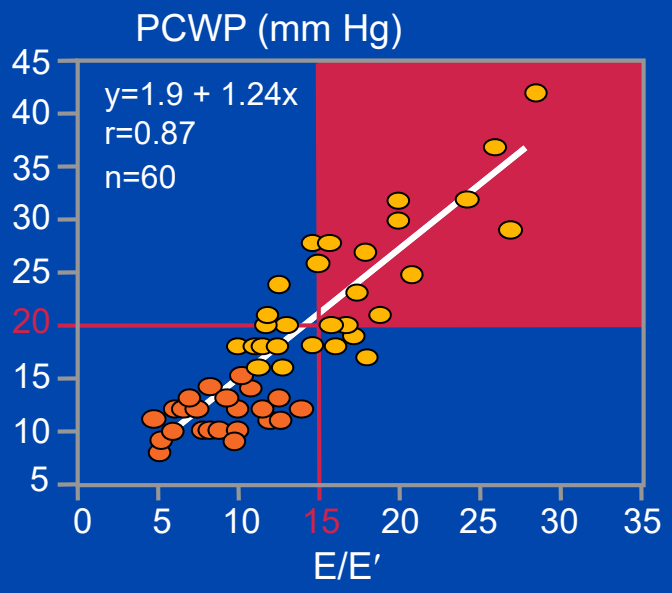
Mitral Inflow and Annulus Velocity



Sohn et al: JACC, 1997

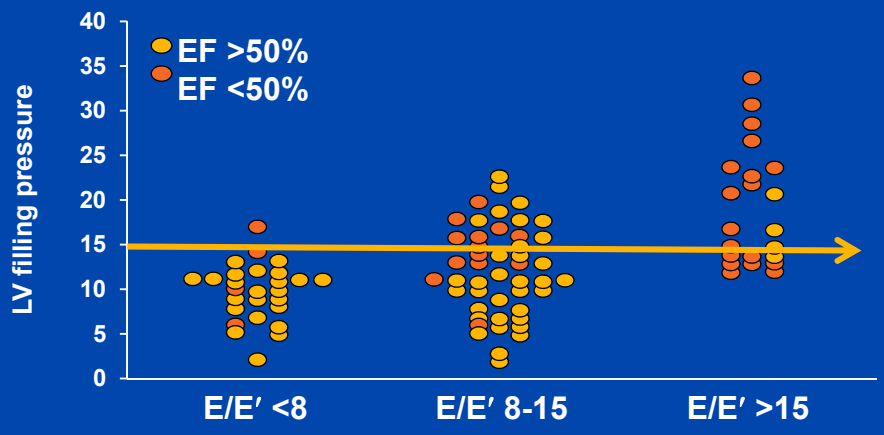
As LV filling pressure ↑

- Mitral E ↑
- Annulus E´ ↓
- E/E´ ↑



Nagueh et al: JACC, 1997
Ommen et al: Circ, 2000

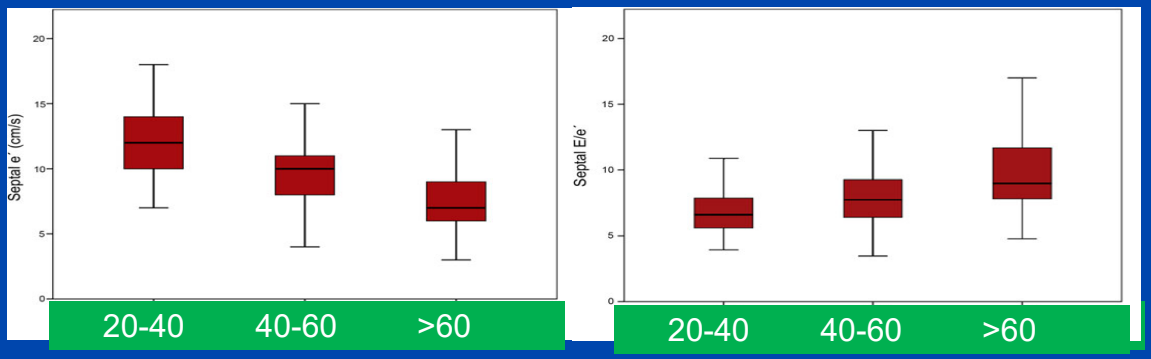
Estimation of LV Filling Pressures
E/e' (Medial MV annulus)



Ommen SR et al: Circulation 102:1788, 2000

What are normal values for e' and E/e' ?

Echocardiographic reference ranges for normal cardiac Doppler data: results from the NORRE Study



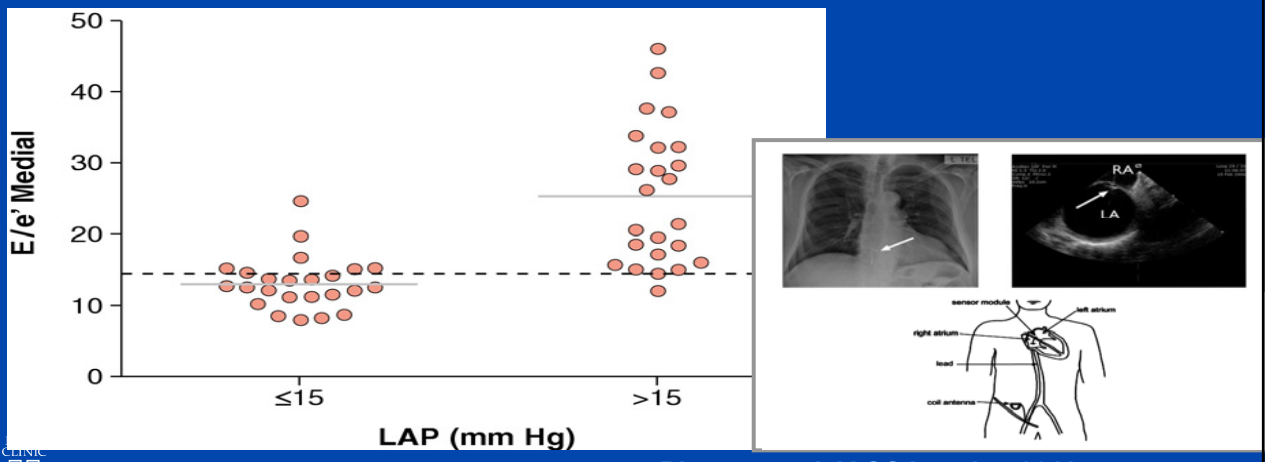
Septal e' based on Age Groups

Septal E/e' based on Age Groups

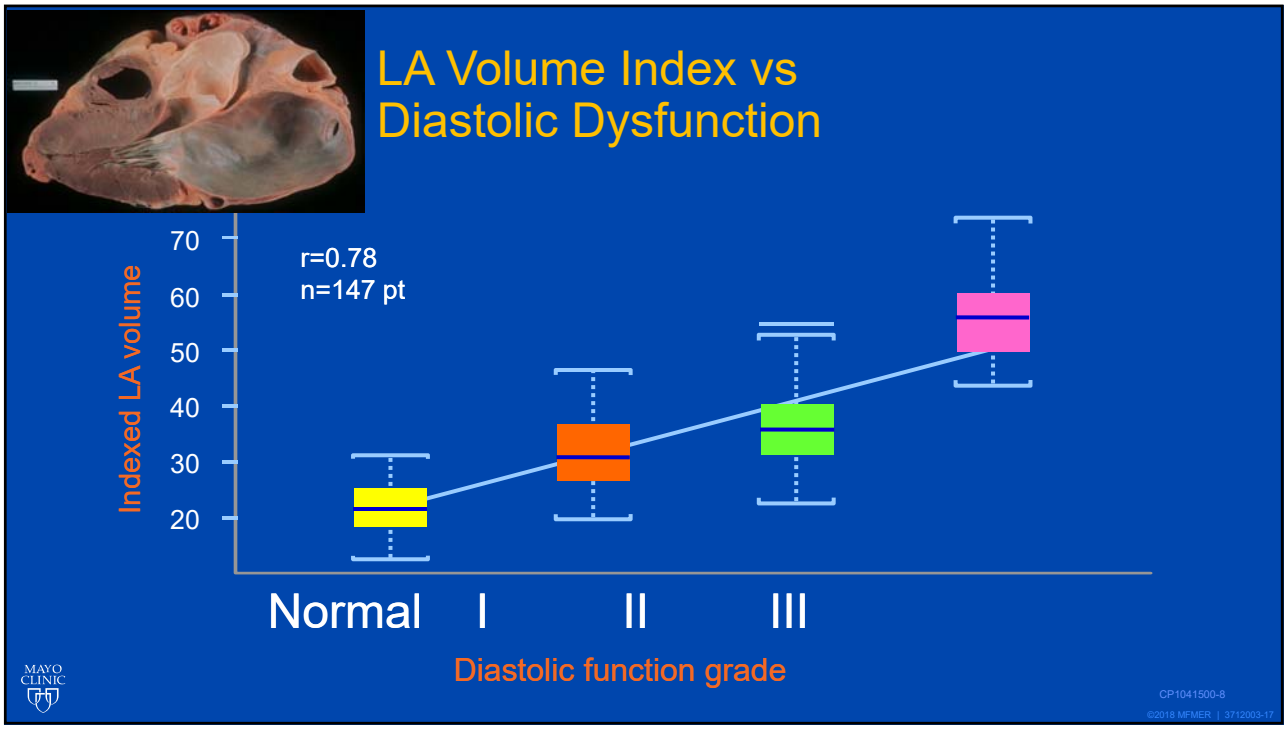
Luis Caballero et al. EHJ 2015

ORIGINAL RESEARCH

Serial Doppler Echocardiography and Tissue Doppler Imaging in the Detection of Elevated Directly Measured Left Atrial Pressure in Ambulant Subjects With Chronic Heart Failure



Ritzema et al JACC Imaging 2011


LA Volume Index vs
Diastolic Dysfunction
r=0.78
n=147 pt
Indexed LA volume
70
60
50
40
30
20
Normal
I
II
III
Diastolic function grade
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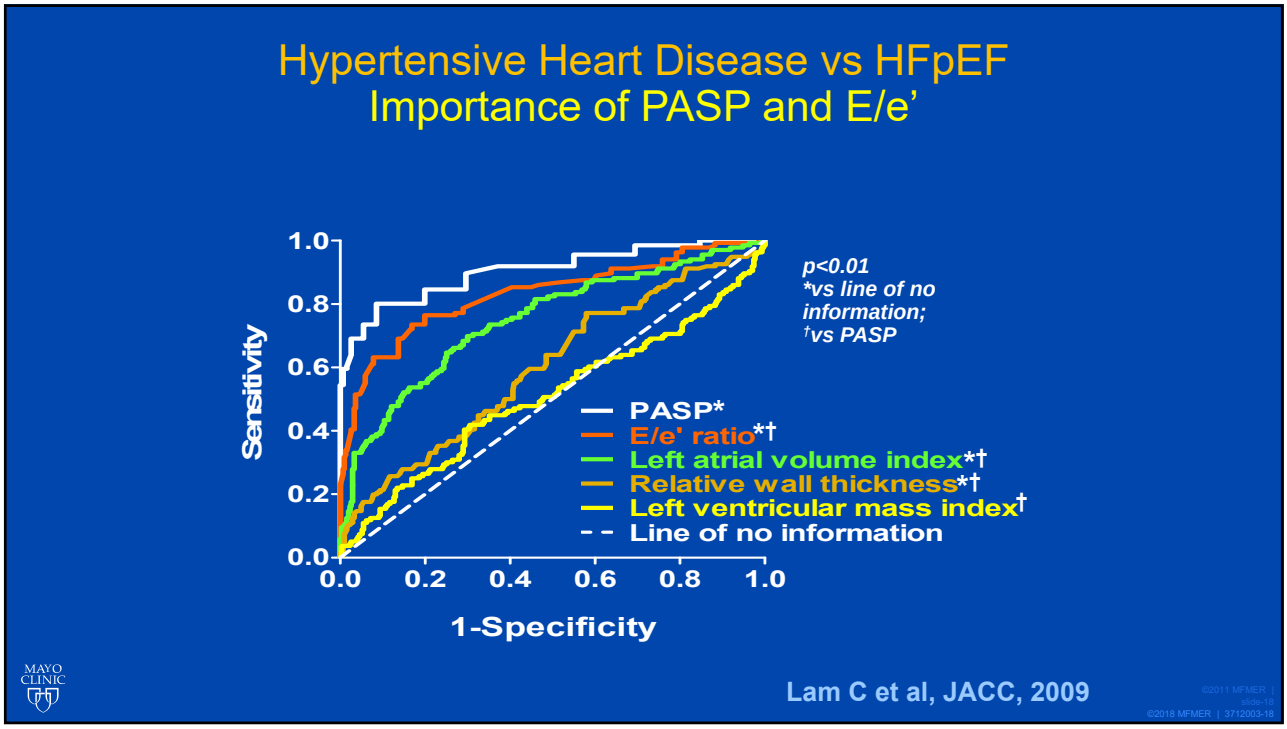
Hypertensive Heart Disease vs HFpEF
Importance of PASP and E/e'
Sensitivity
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1-Specificity
p<0.01
*vs line of no information;
†vs PASP
PASP*
E/e' ratio*†
Left atrial volume index*†
Relative wall thickness*†
Left ventricular mass index†
Line of no information
Lam C et al, JACC, 2009
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ASE/EACVI GUIDELINES AND STANDARDS

Recommendations for the Evaluation of Left Ventricular Diastolic Function by Echocardiography: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging

Sherif F. Nagueh, Chair, MD, FASE,[1] Otto A. Smiseth, Co-Chair, MD, PhD,[2] Christopher P. Appleton, MD,[1] Benjamin F. Byrd, III, MD, FASE,[1] Hisham Dokainish, MD, FASE,[1] Thor Edvardsen, MD, PhD,[2] Frank A. Flachskampf, MD, PhD, FESC,[2] Thierry C. Gillebert, MD, PhD, FESC,[2] Allan L. Klein, MD, FASE,[1] Patrizio Lancellotti, MD, PhD, FESC,[2] Paolo Marino, MD, FESC,[2] Jae K. Oh, MD,[1] Bogdan Alexandru Popescu, MD, PhD, FESC, FASE,[2] and Alan D. Waggoner, MHS, RDCS[1], *Houston, Texas;*

Four Major Diagnostic Parameters Normal Values

1. E' velocity ≥ 7(med), 10 (lat) cm/s
2. E/e' ≤ 14 (Av), 15(Med)
3. TR velocity ≤ 2.8 m/sec
4. LAVI ≤ 34 mL/m^2

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JASE and EJ CV Imaging April 2016

New Criteria for Diastolic Function Assessment

In pts with normal LVEF≥ 50%

1 – Septal e' velocity ≥7 cm/s or lateral e' velocity ≥10 cm/s
2 – Average E/e' ≤14 , 15 (Med)
3 – TR velocity ≤2.8 m/s
4 – LA volume index ≤34 mL/m^2

≥ 3 Normal	2 and 2	≥ 3 Abnormal
Normal diastolic function	Indeterminate	Diastolic dysfunction

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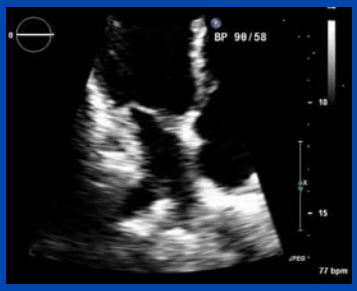
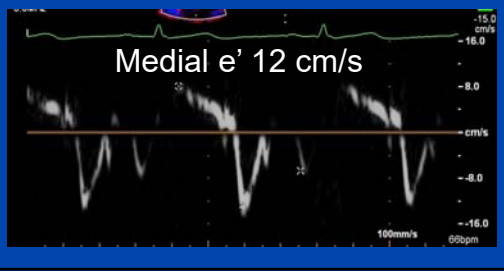
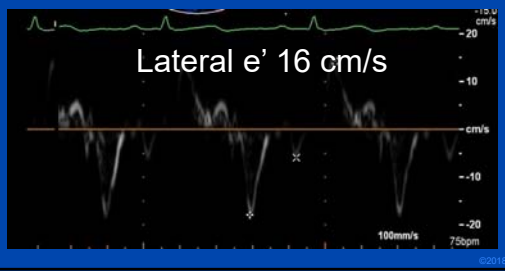
Criteria for diagnosis of LV diastolic dysfunction in patients with normal LVEF in JASE 2016

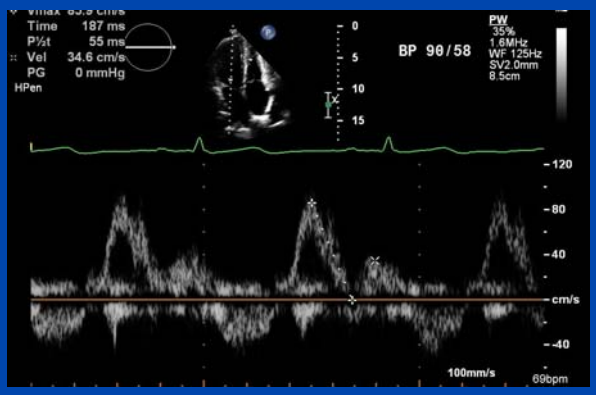
Normal Diastolic Function

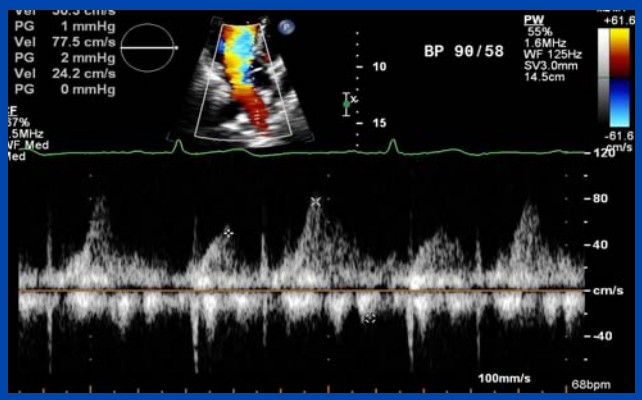




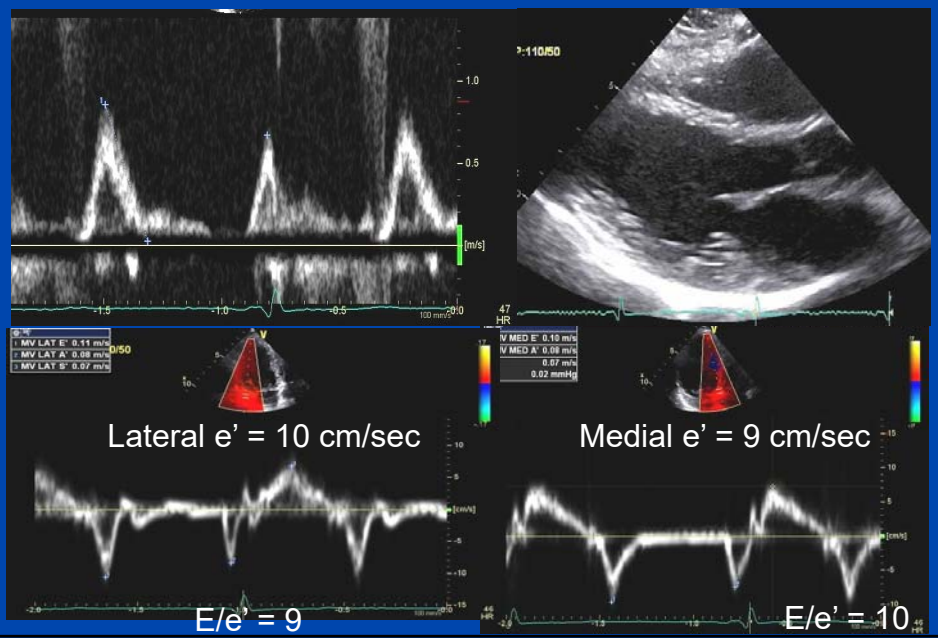


True Normal Diastolic Function





71 year old woman with LAVI = 39 mL/m²



E/e' NL < 14
e' NL > 7
LAVI Enlarged
TR NL < 2.8

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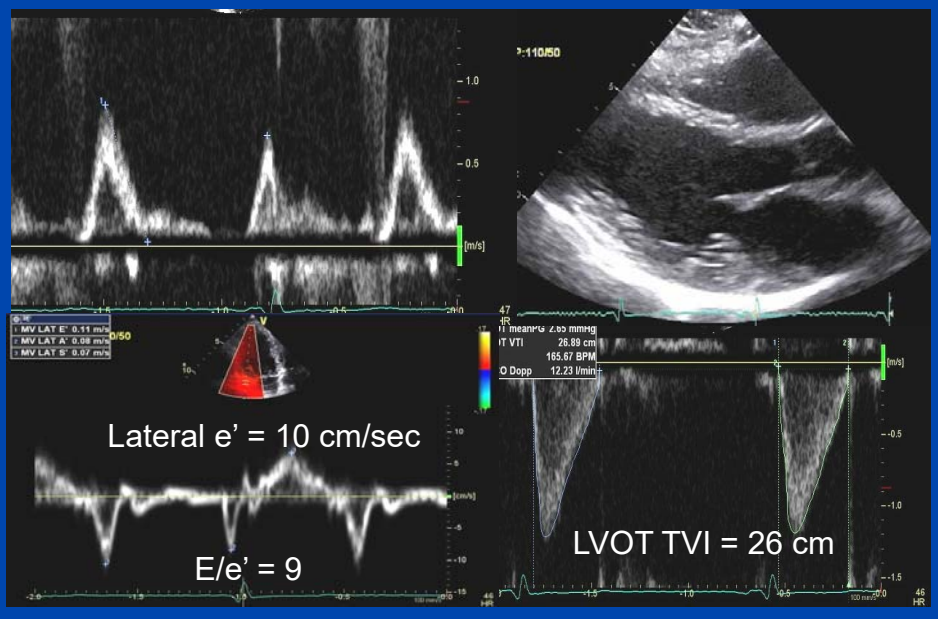
71 year old woman with LAVI = 39 mL/m²



E/e' NL < 14
e' NL > 7
LAVI Enlarged
TR NL < 2.8

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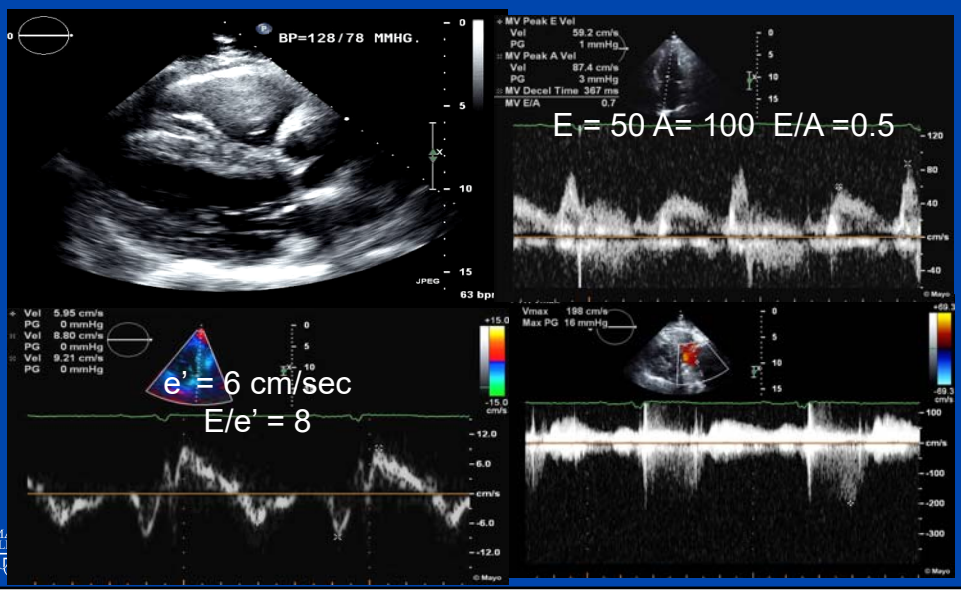
Reasons for LA enlargement

- Diastolic dysfunction
- Increased filling pressure
- Increased volume
- Athlete's heart
- Measurement error

Normal or Grade 1 Diastolic Dysfunction ?
LAVI 28 mL/m^2



E/e' NL < 14
e' ABNL < 7
LAVI Normal
TR NL < 2.8

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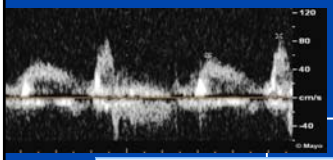
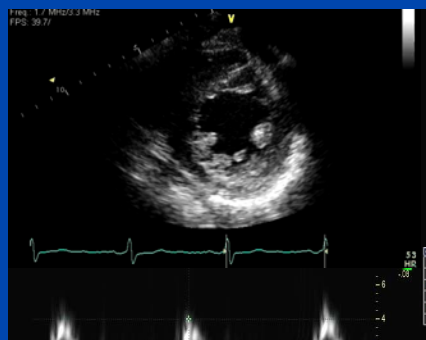
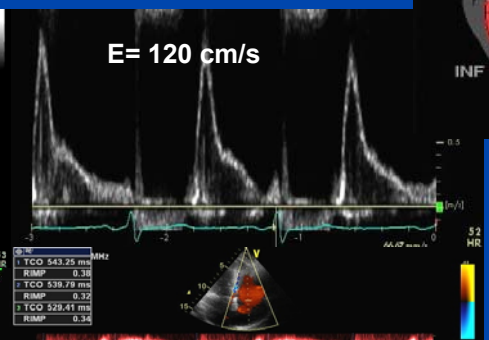


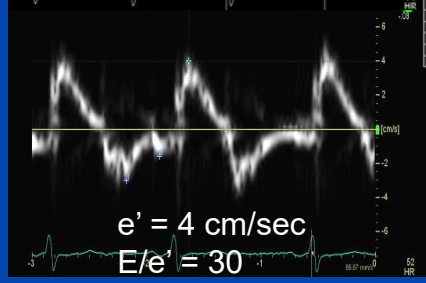
≥ 3 Normal	2 and 2	≥ 3 Abnormal
Normal dia[illegible]c function	Indeterminate	Diastolic dysfunction
Normal Diastolic Filling Pressure		Increased Diastolic Filling Pressure

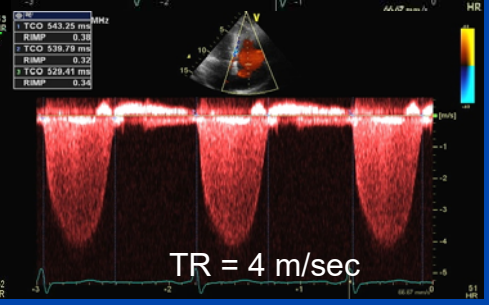
Criteria for diagnosis of LV dias[illegible]/EF

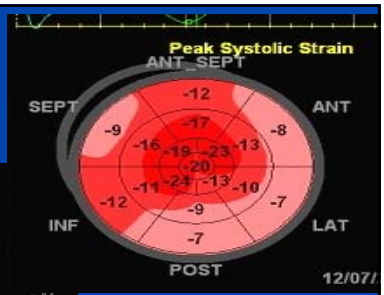
Diastolic Function?











e' ABNL < 7
E/e' ABNL > 14
LAVI ??
TR NL > 2.8

New Criteria for Diastolic Function Assessment

In pts with normal LVEF≥ 50%

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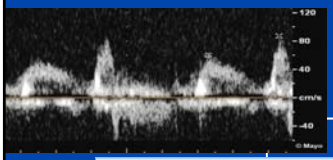


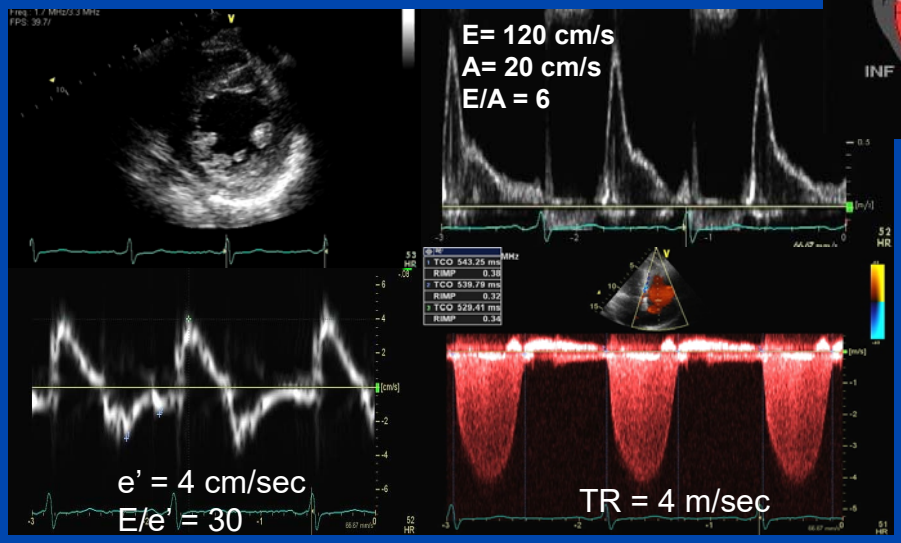
≥ 3 Normal	2 and 2	≥ 3 Abnormal
Normal dia[illegible]c function	Indeterminate	Diastolic dysfunction
Normal Diastolic Filling Pressure		**Increased Diastolic Filling Pressure**

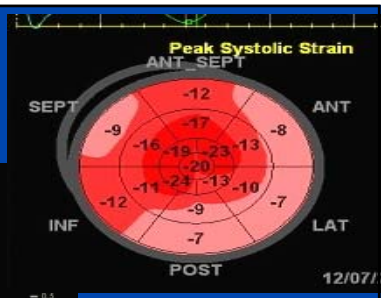
Criteria for diagnosis of LV diast[illegible]EF

Diastolic Function Assessment Take Home Point #1

- LV myocardial relaxation is reduced in all stages of diastolic dysfunction
- Mitral annulus e' velocity reflects myocardial relaxation
- Normal e' = Normal diastolic function
- Algorithm #1 separates normal filling from elevated filling pressure
- Initial assessment of diastolic functon is based on
  - E', E/e', TR velocity, and LAVI

Diastolic Function?





e' ABNL < 7
E/e' ABNL > 14
LAVI ??
TR NL > 2.8

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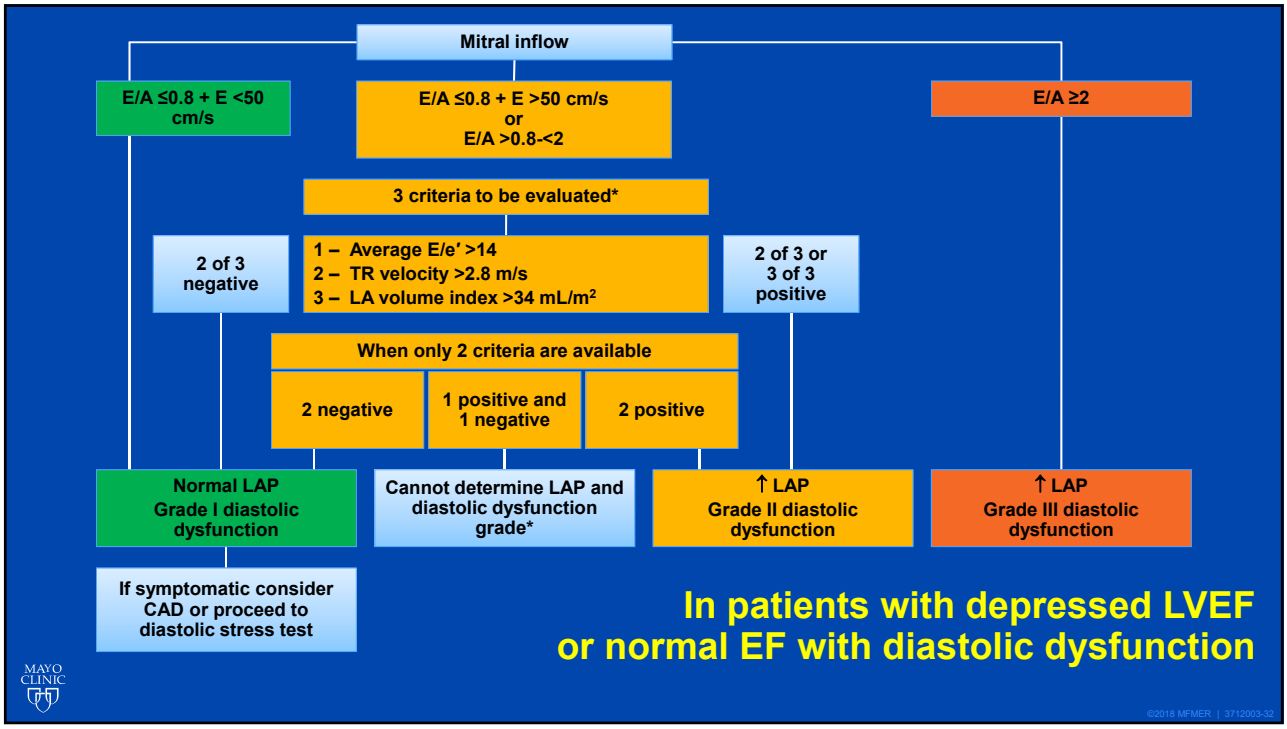

In patients with depressed LVEF or normal EF with diastolic dysfunction

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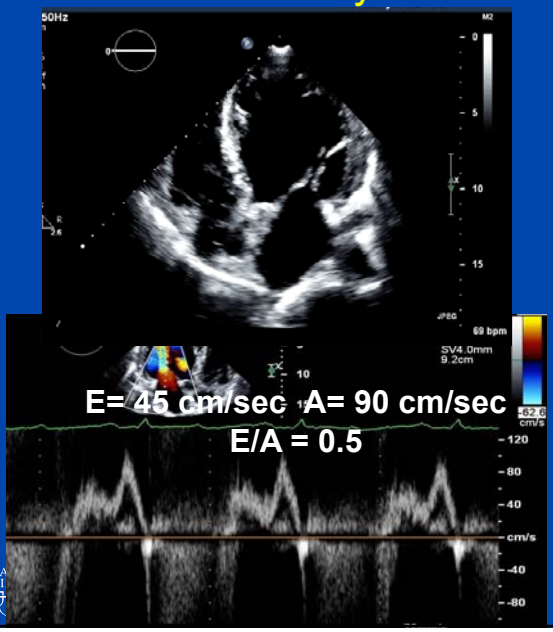
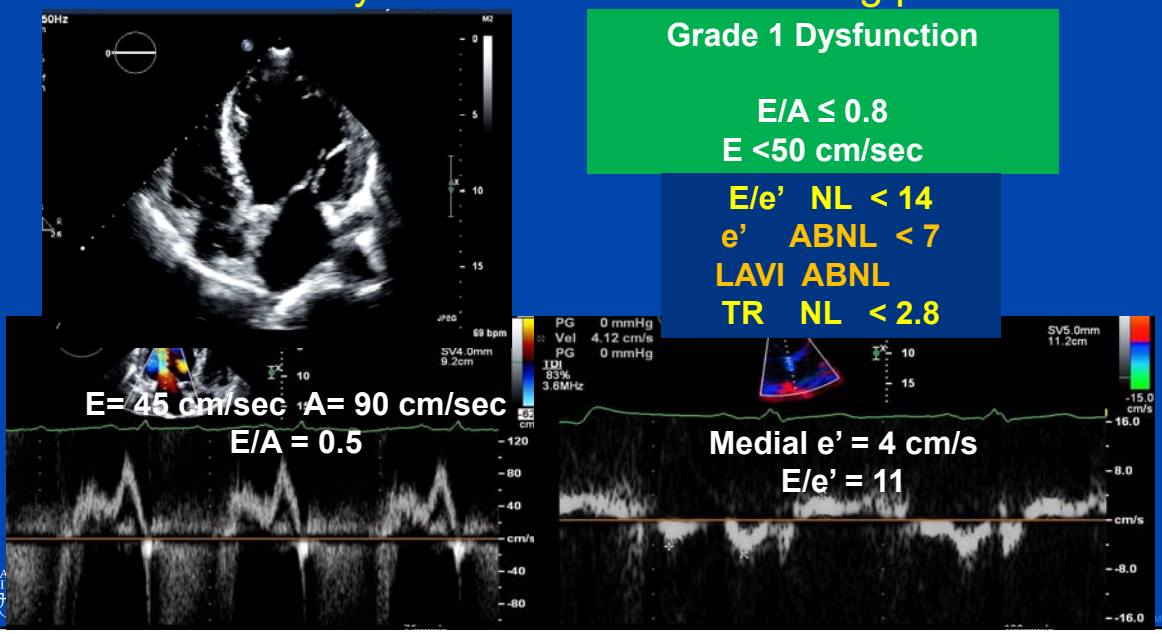
67 yo man with ischemic CM and HF
Gr. 1 dysfunction with normal filling pressure



Grade 1 Dysfunction

E/A ≤ 0.8
E <50 cm/sec

67 yo man with ischemic CM and HF
Gr. 1 dysfunction with normal filling pressure



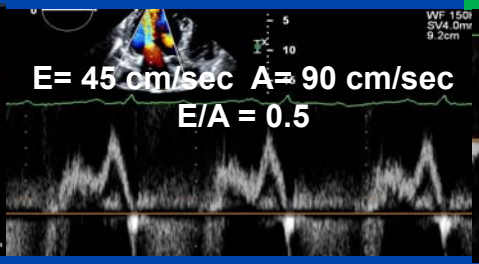
Grade 1 Dysfunction

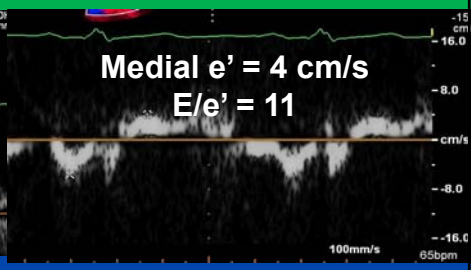
E/A ≤ 0.8
E <50 cm/sec

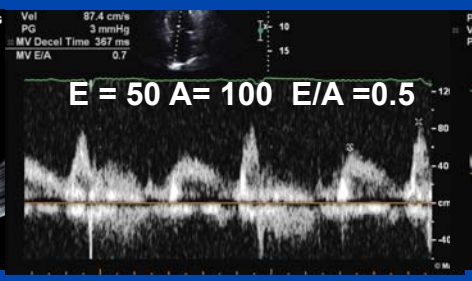
E/e' NL < 14
e' ABNL < 7
LAVI ABNL
TR NL < 2.8

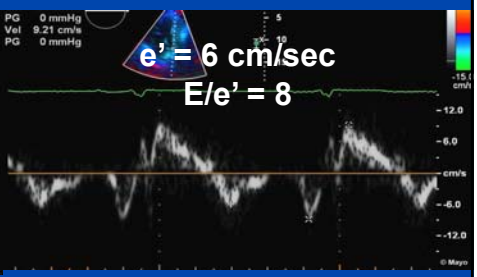
Grade 1 Diastolic Dysfunction

Grade 1 Dysfunction
E/A ≤ 0.8
E <50 cm/sec

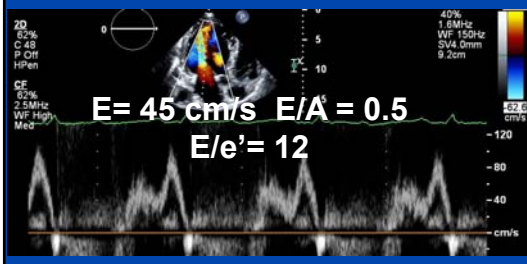


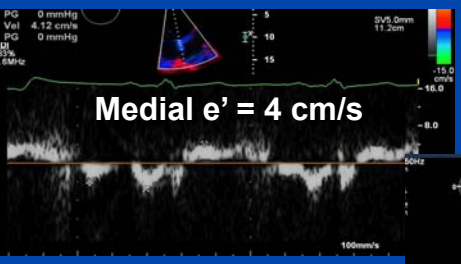




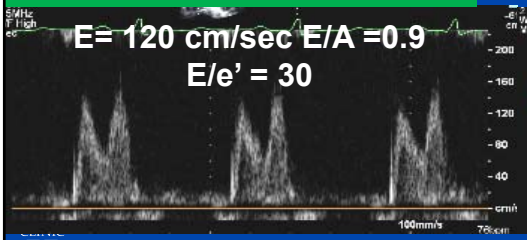


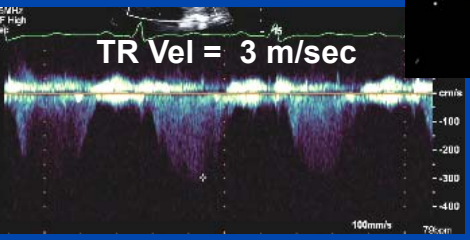
67 year old man with ischemic CM and HF



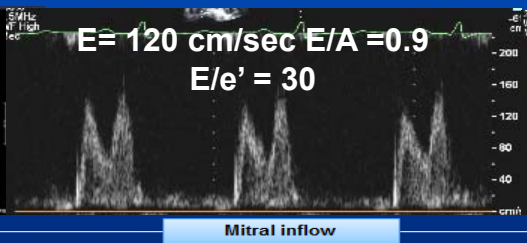


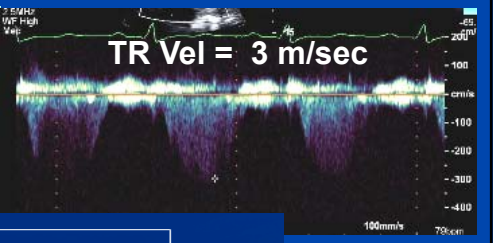
2 months before

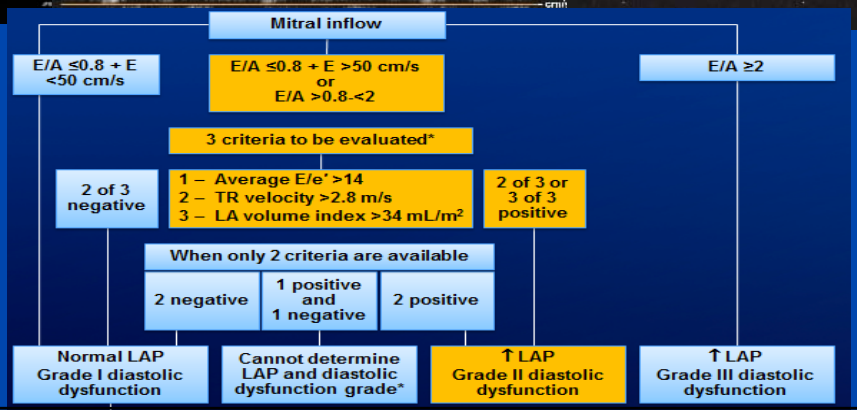




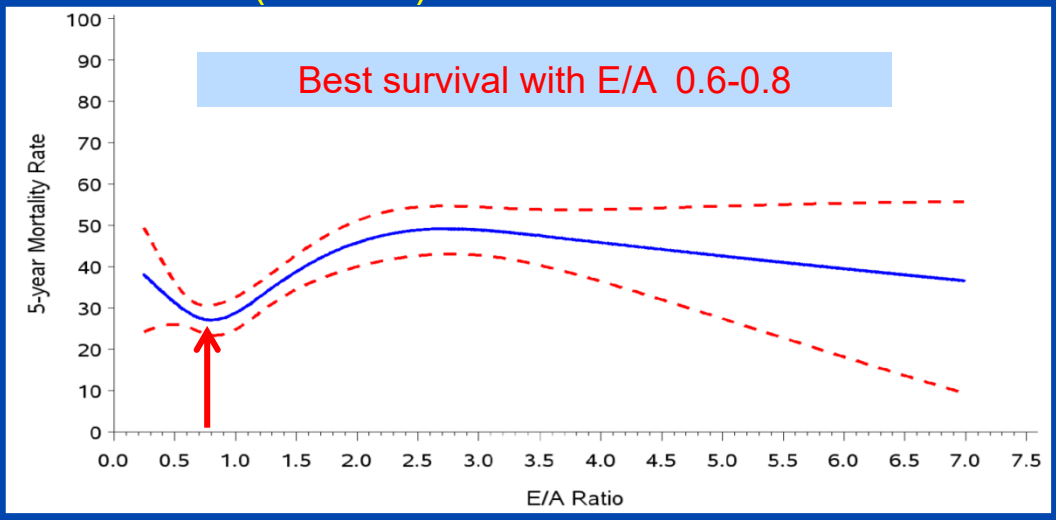
67 yo man with ischemic CM and HF
Gr. 2 dysfunction with increased filling pressure





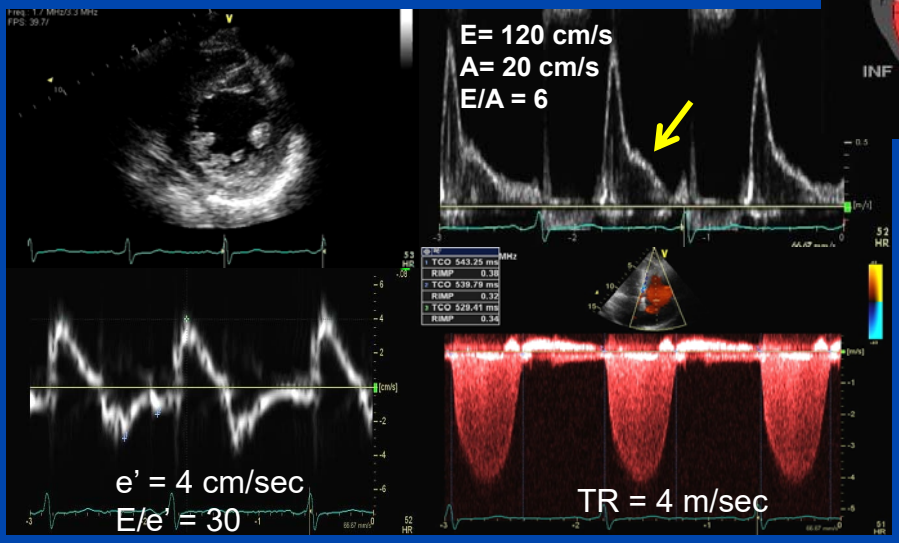


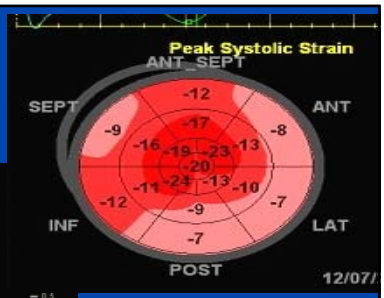
Ischemic Cardiomyopathy Echo Predictor
STICH Trial (N=1511)



Lin et al. 2014 AHA

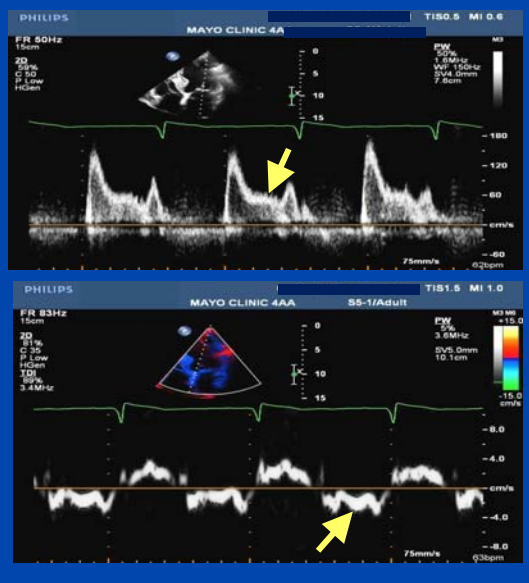
Grade 3 Dysfunction
L wave

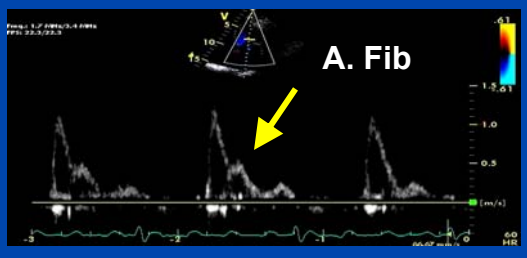




e' ABNL < 7
E/e' ABNL > 14
LAVI ??
TR NL > 2.8

Mid-diastolic mitral flow (L)
Delayed relaxation





Frommelt et al: J Am Soc Echocardiogr 16:176, 2003

Distribution of 2D and Doppler Variables

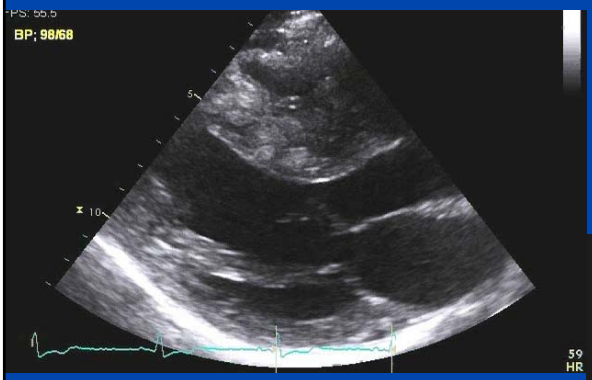
		Elevated filling pressure (n=165)	Normal filling pressure (n=155)
Mitral E/A ratio ≤0.8 + E ≤50 cm/s		0	23
Mitral E/A ratio ≥2		53	5
None of the cutoff values met for the 3 variables in patients with diastolic dysfunction		15	70
3 abnormal	LAV >34 ML/m^2, E/e′ >14, and TRV >2.8 m/s	25	0
2 abnormal (2 of 3 listed)	LAV >34 mL/m^2, E/e′ >14, TRV <2.8 m/s	35	7
	LAV >34 mL/m^2, E/e′ <14, TRV >2.8 m/s	11	8
	LAV <34 mL/m^2, E/e′ >14, TRV >2.8 m/s	8	1
1 abnormal	LAV >34 mL/m^2	6	32
	E/e′ >14	8	4
	TR >2.8 m/s	4	5

- Normal Filling Pressure
  - 3 normal parameters
  - LAVI >34 mL/m^2
  - E/A ≤ 0.8 + E ≤ 50 cm/s
- Increased Filing pressure
  - E/A ≥2
  - E/e' > 14 + LAVI >34 mL/m^2
  - 3 abnormal
  - 2 abnormal

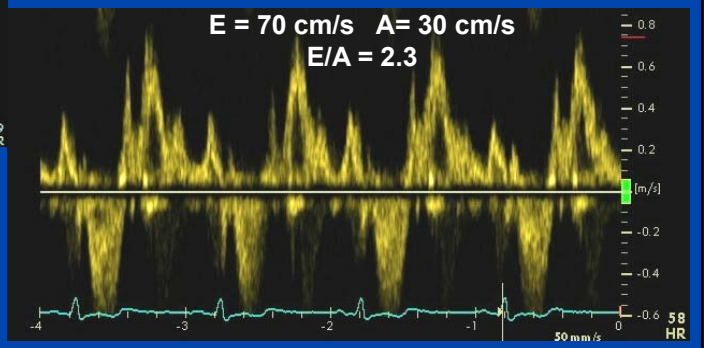
MAYO CLINIC

Andersen et al: J Am Coll Cardiol 2017;69:1937-48

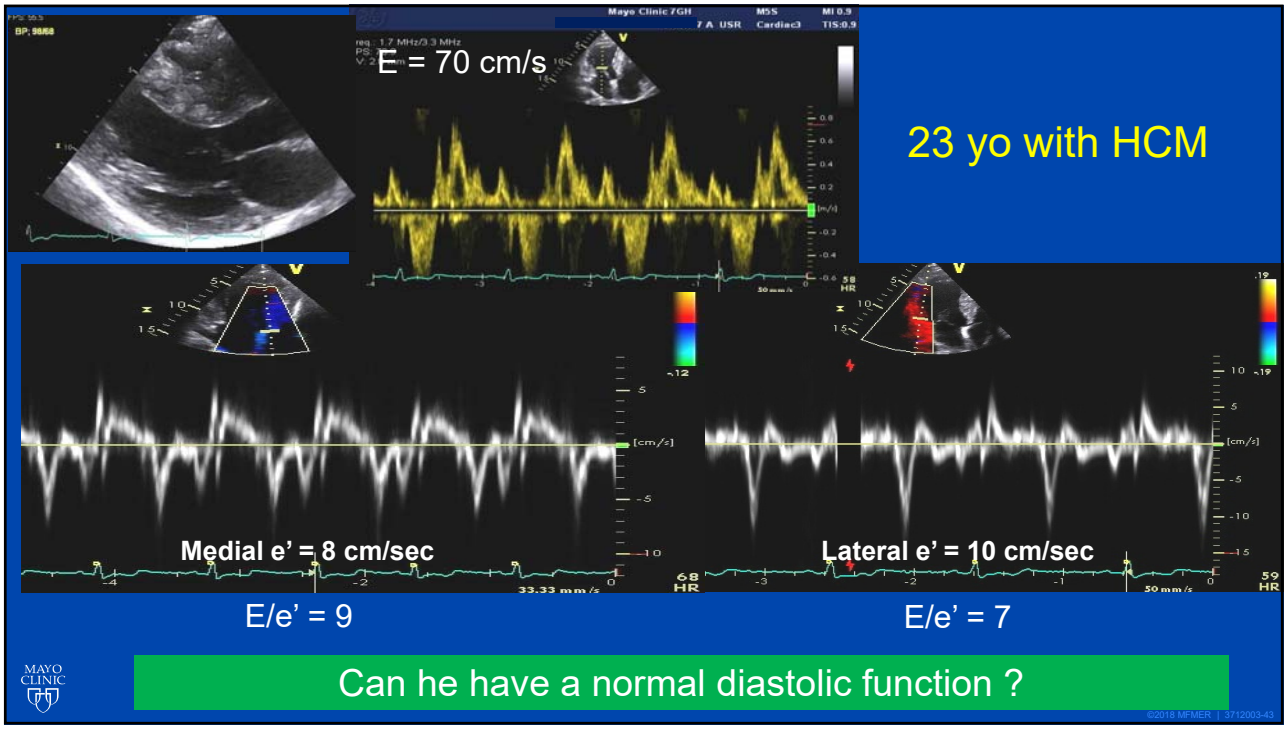
23 YO with HCM

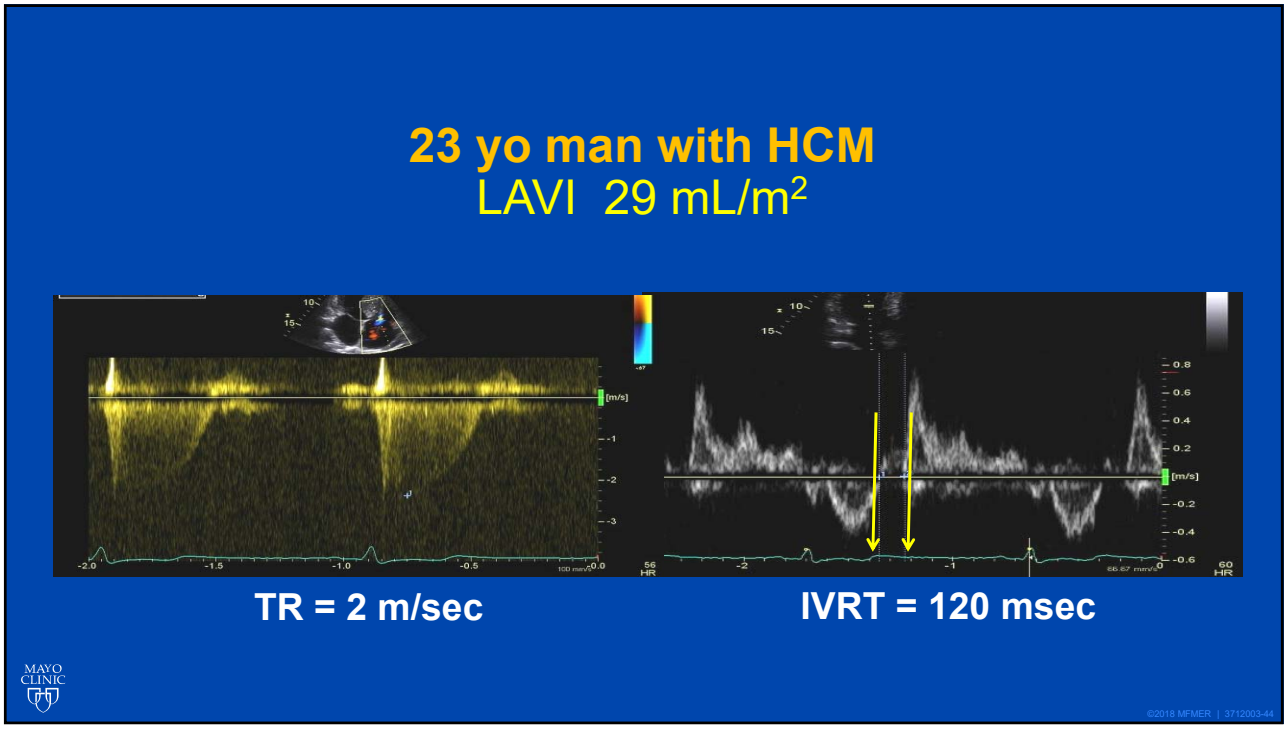


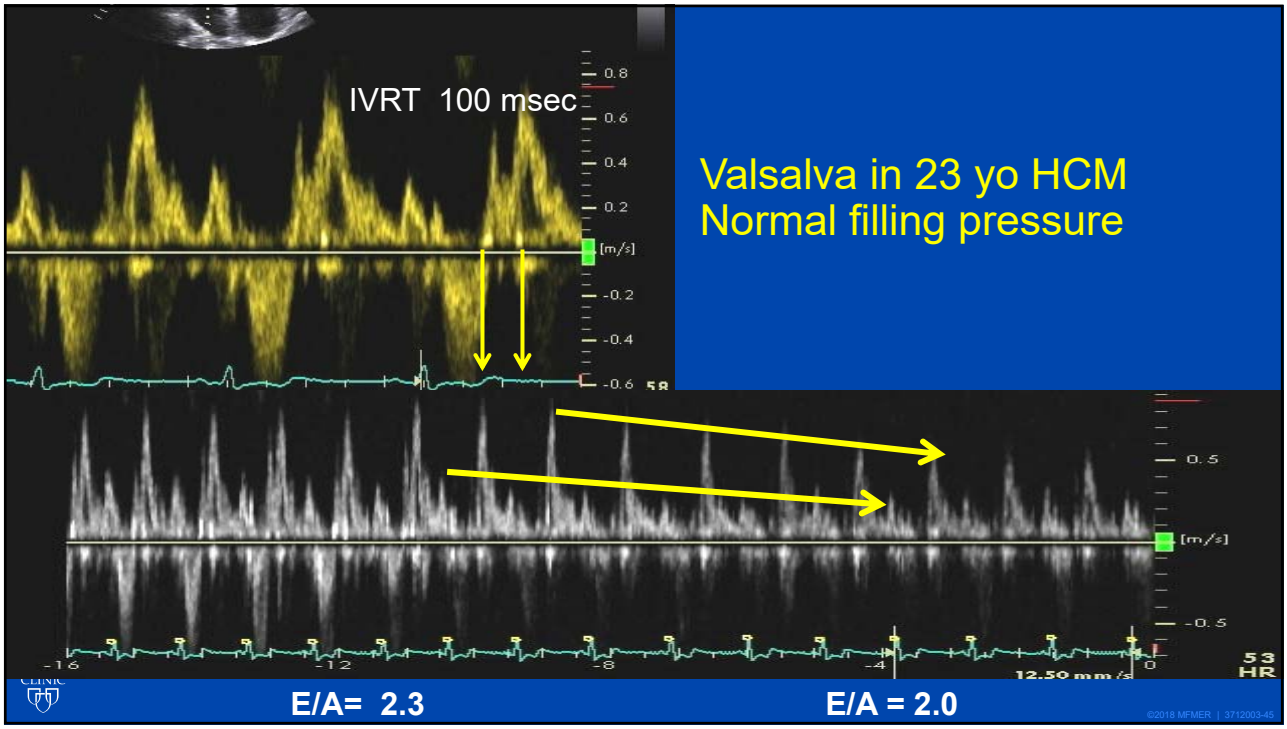
1. Grade 1
2. Grade 2
3. Grade 3
4. Possibly normal

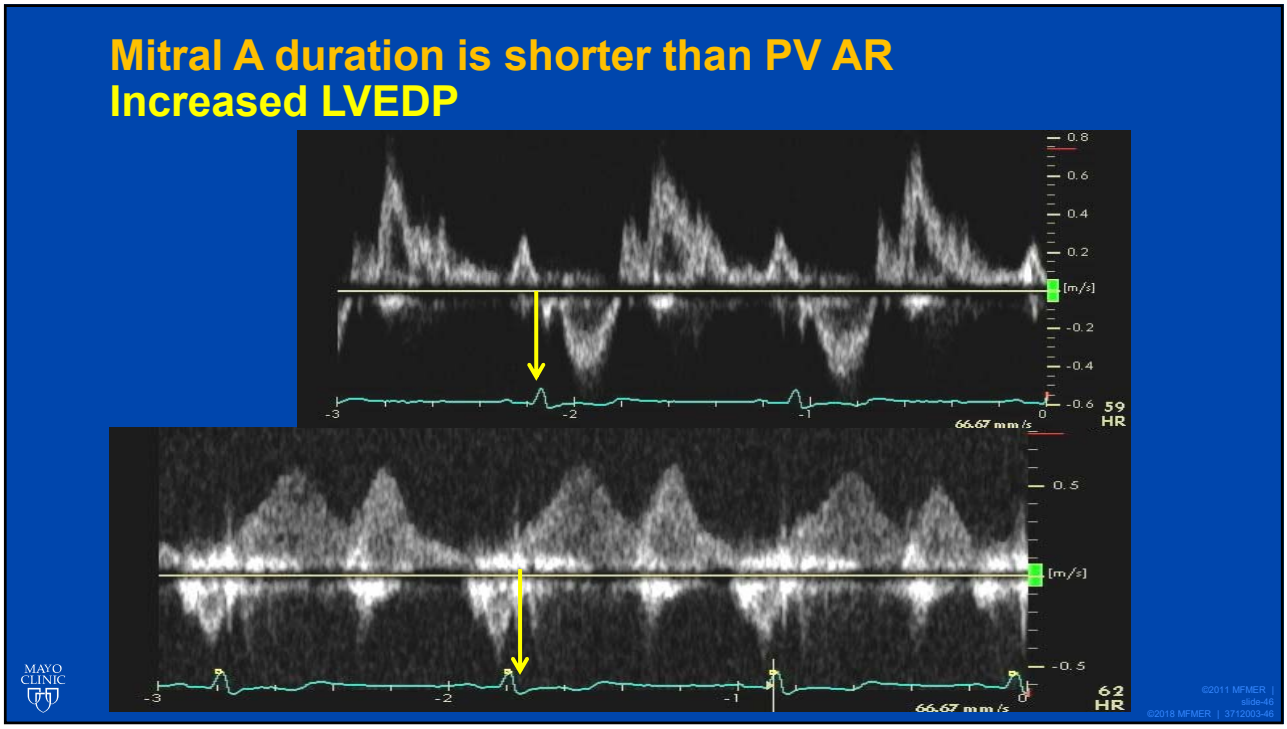


MAYO CLINIC

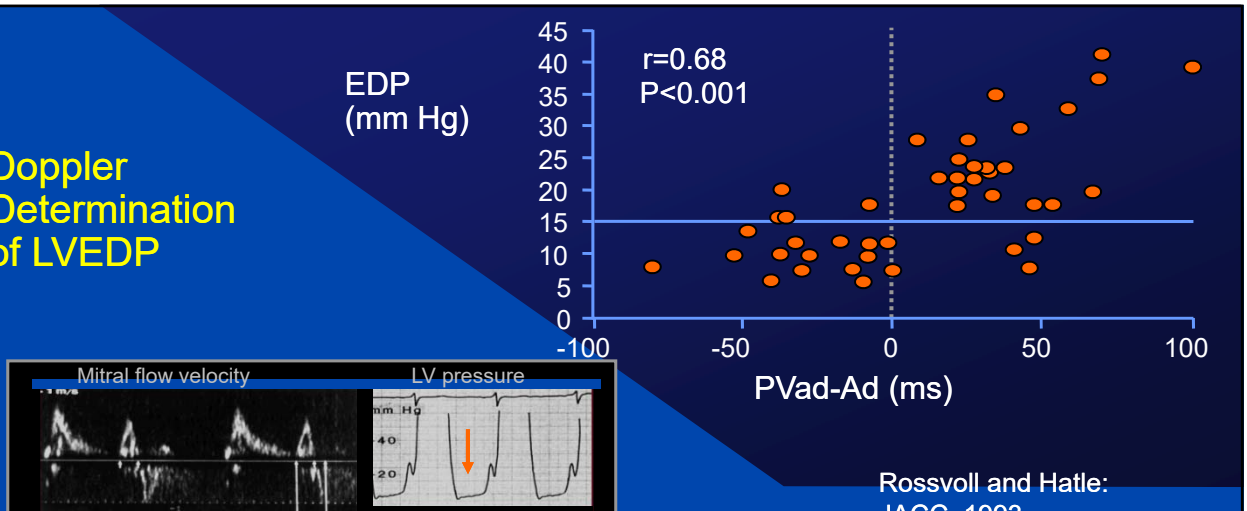

E = 70 cm/s
23 yo with HCM
Medial e' = 8 cm/sec
Lateral e' = 10 cm/sec
E/e' = 9
E/e' = 7
Can he have a normal diastolic function ?

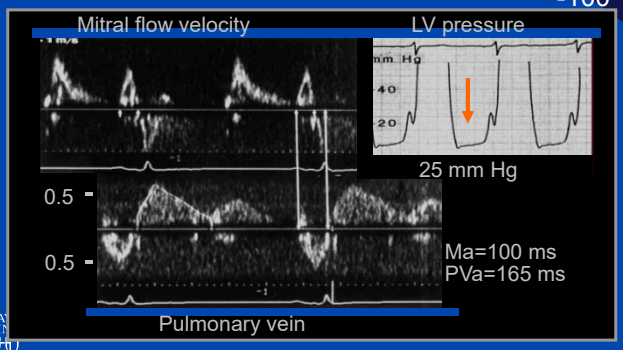

23 yo man with HCM
LAVI 29 mL/m2
TR = 2 m/sec
IVRT = 120 msec


IVRT 100 msec
Valsalva in 23 yo HCM
Normal filling pressure
E/A= 2.3
E/A = 2.0


Mitral A duration is shorter than PV AR
Increased LVEDP

Doppler Determination of LVEDP





Rossvoll and Hatle: JACC, 1993

LVEDP can be increased with normal mean LV diastolic pressure

Diastolic Function Assessment Take Home Message #2

- Grade 1 diastolic dysfunction is the best pattern for the patients with Heart Failure
- Evidence for diastolic dysfunction needs an objective evidence
  - Hypertension
  - Hypertrophic CM
  - Old age

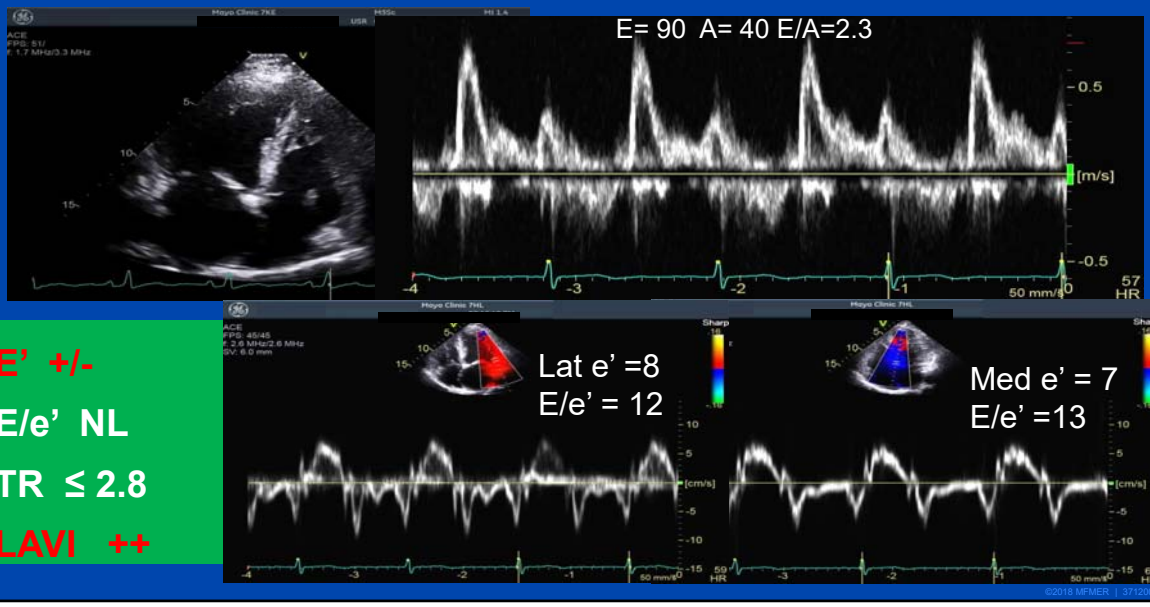
The best evidence is reduced relaxation
Reduced e'
L wave
Prolonged IVRT

Difficult Situations

- Assess diastolic function or filling pressure in
  - 2 normal and 2 abnormal
  - HCM
  - LBBB
  - MAC
  - Atrial Fibrillation
- Additional supportive parameters
  - Pulmonary vein
  - Valsalva
  - IVRT and timing intervals
  - Strain

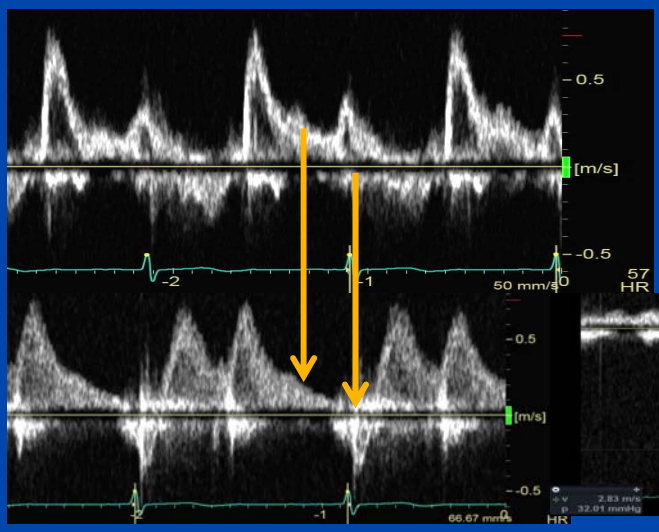
67 year old woman with HPT and SOB

LAVI = 54 and TR= 2.8 m/s

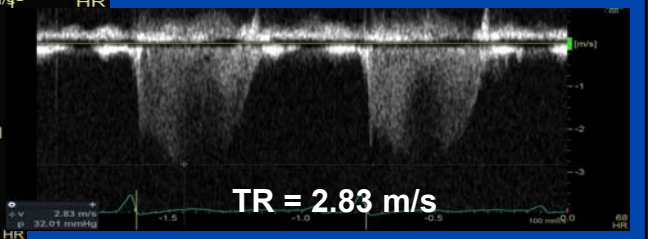


1. E' +/-
2. E/e' NL
3. TR ≤ 2.8
4. LAVI ++

Indeterminate ?



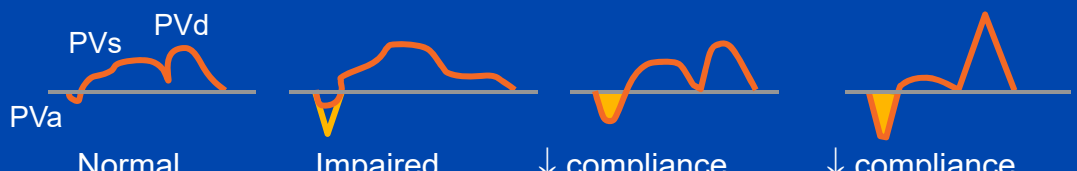
- E’ +/-
- E/e’ < 15
- LA > 34
- TR > 2.8 m/sec

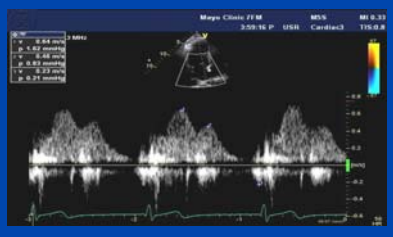


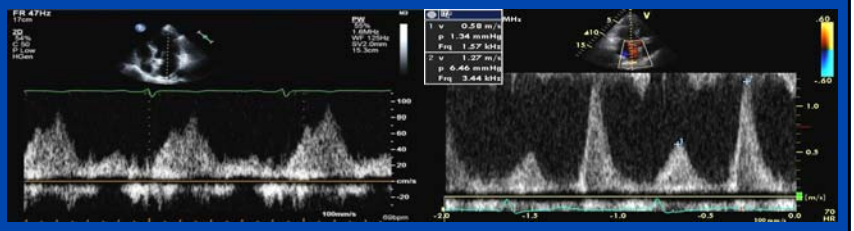
MAYO CLINIC

Pulmonary Vein Velocity

PVs decreases as filling pressure increases







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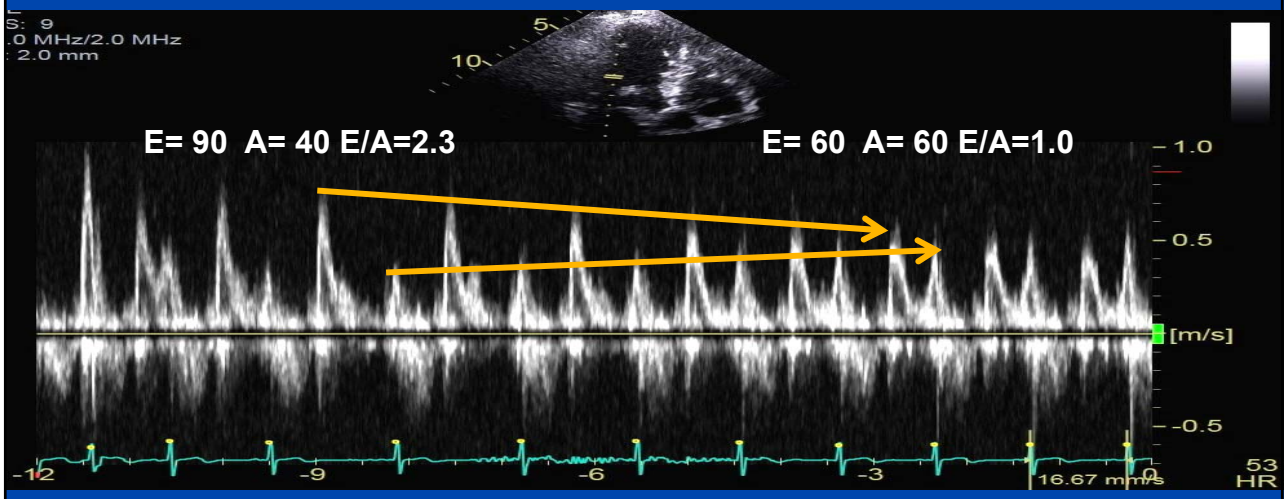
Valsalva Maneuver : E/A reduced > 0.5
Grade 2 Dysfunction



MAYO CLINIC

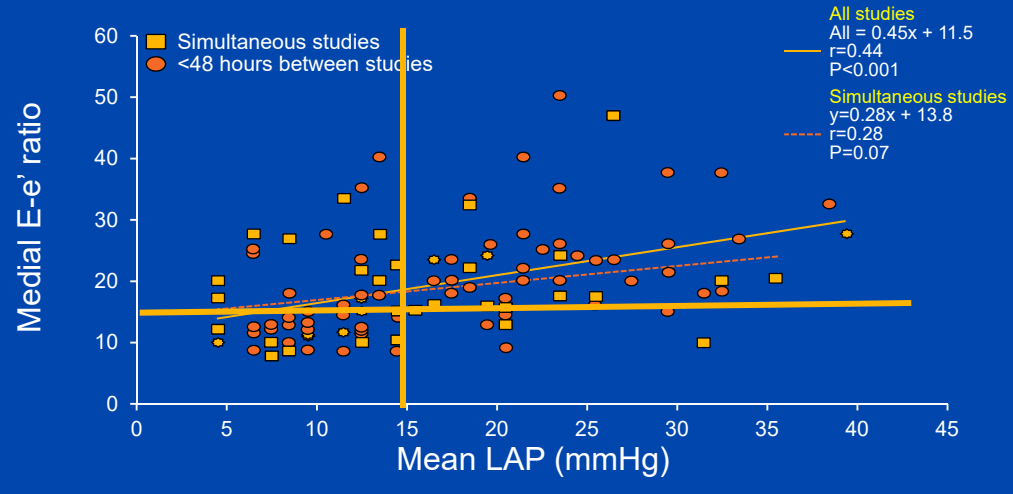
Evaluation of Left Ventricular Filling Pressures by Doppler Echocardiography in Patients With Hypertrophic Cardiomyopathy
Correlation With Direct Left Atrial Pressure Measurement at Cardiac Catheterization

Jeffrey B. Geske, MD; Paul Sorajja, MD; Rick A. Nishimura, MD; Steve R. Ommen, MD

Conclusions—In 100 symptomatic patients with HCM, Doppler echo estimates of LV filling pressure correlate modestly with direct measurement of LAP. Given the complex nature of diastolic dysfunction in HCM, precise characterization of LV filling pressure in an individual patient cannot be determined with the use of these noninvasive parameters. (***Circulation*. 2007;116:2702-2708.**)

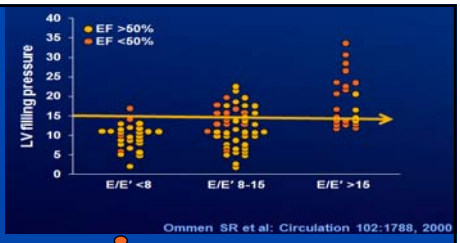
MAYO CLINIC

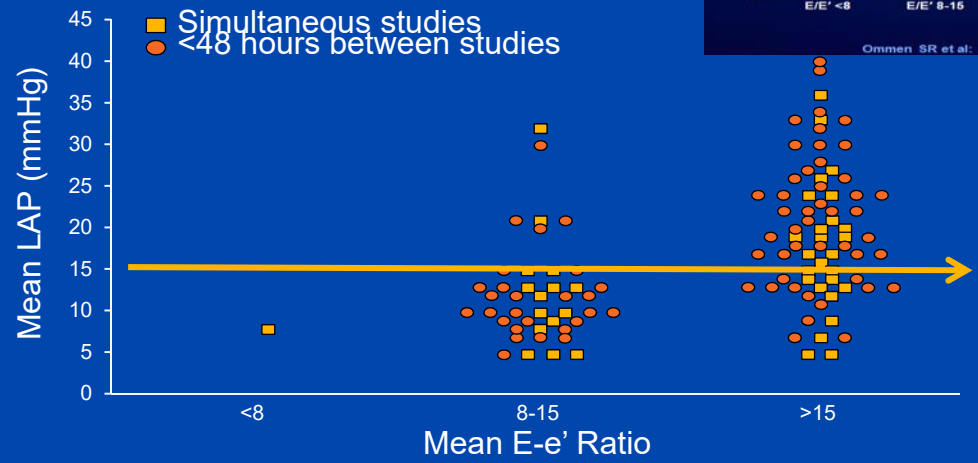
Medial E/e' Ratio Versus Mean LAP



Geske et al: Circulation; 116:2702, 2007

Mean LAP vs Medial E-e' ratio
Hypertrophic CM

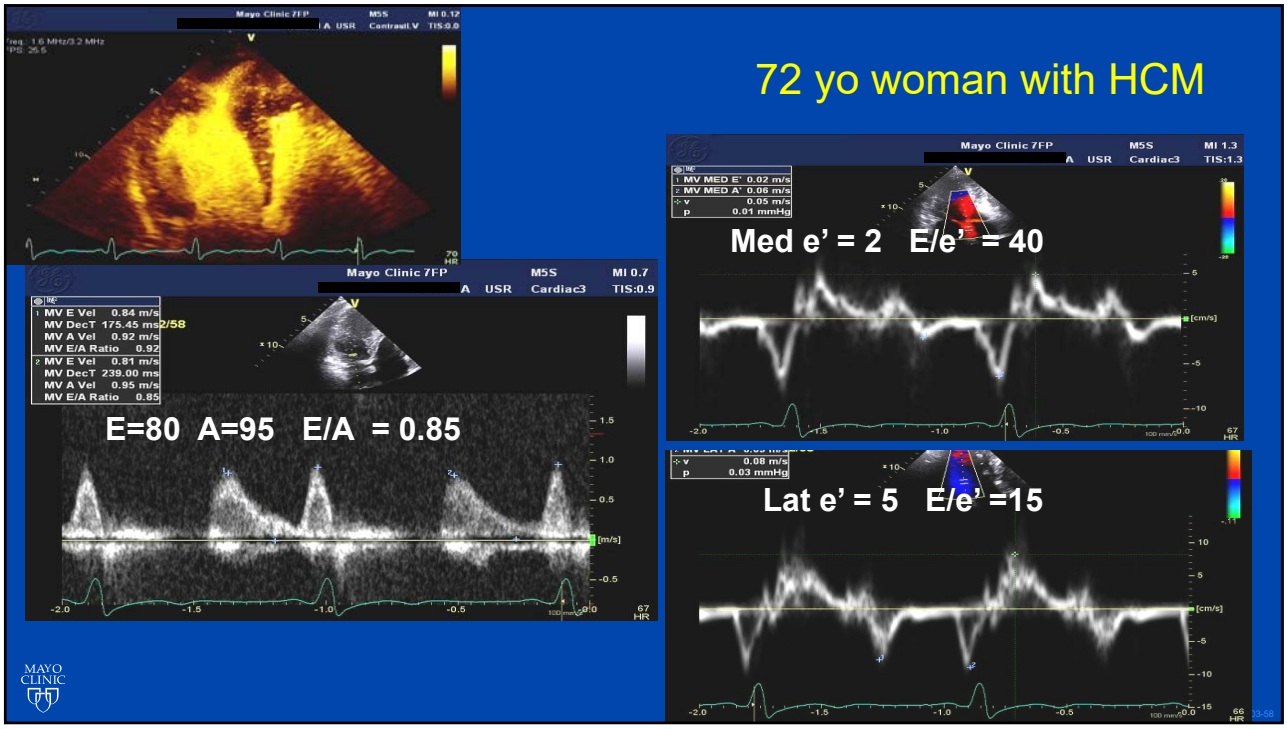




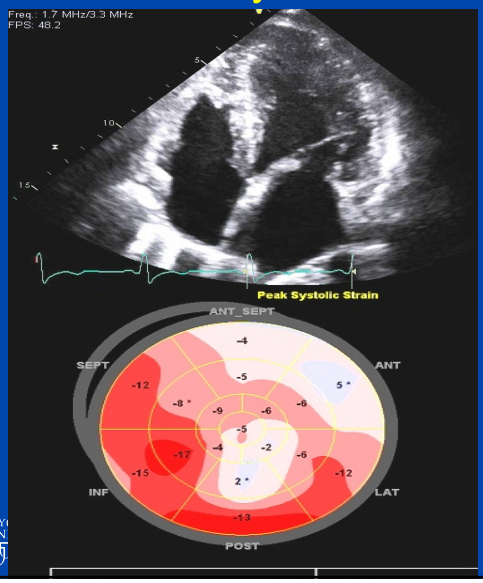
Geske et al: Circulation; 116:2702, 2007

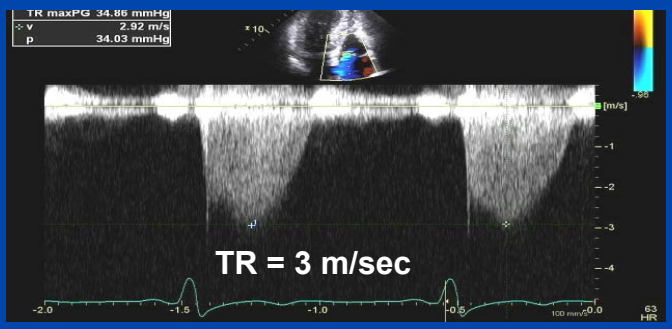
Diastolic Function Evaluation in HCM

- E' velocity is reduced in almost all patients
- E/e' predicts clinical outcome
- Use following parameters (ASE 2016 Guideline)
  - E/e' >15
  - LAVI >34 mL/m^2
  - TR velocity > 2.8 m/sec
  - PV Ar-A duration ≥ 30 msec
- The majority rules



72 yo woman with apical HCM
Grade 2 dysfunction with LAVI 37 mL/m^2

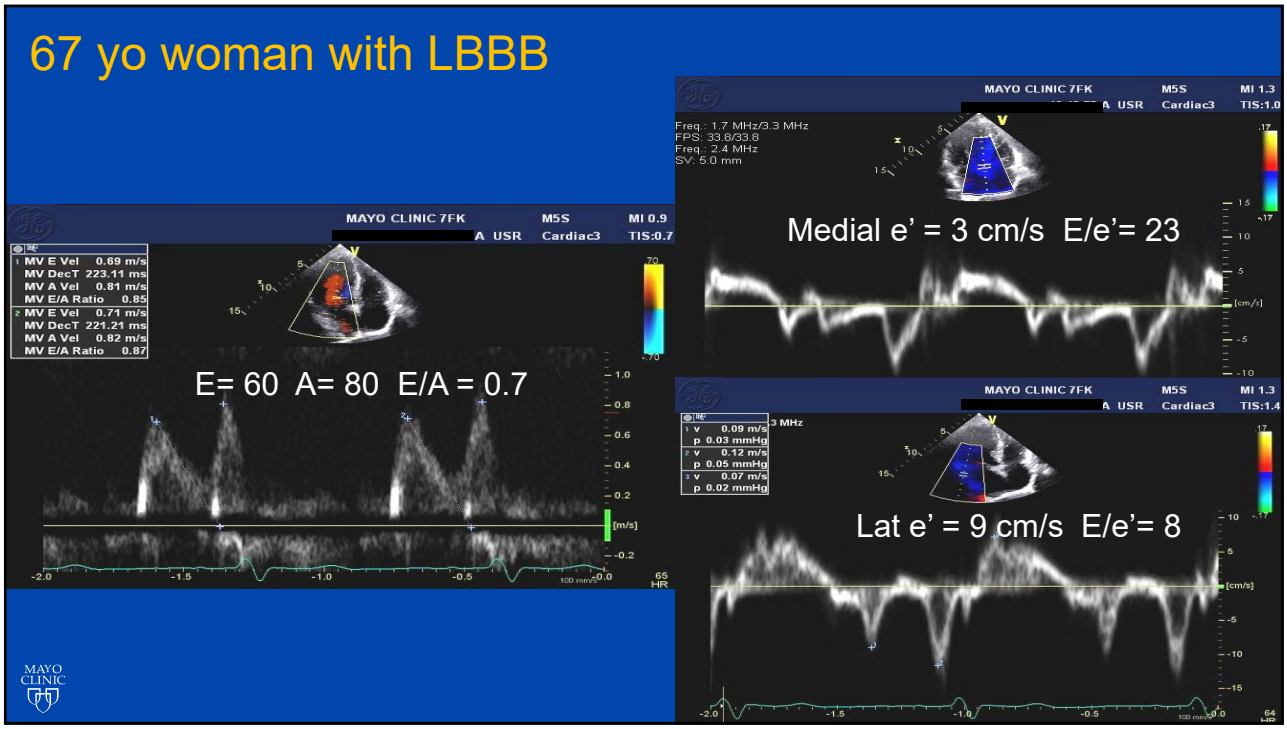




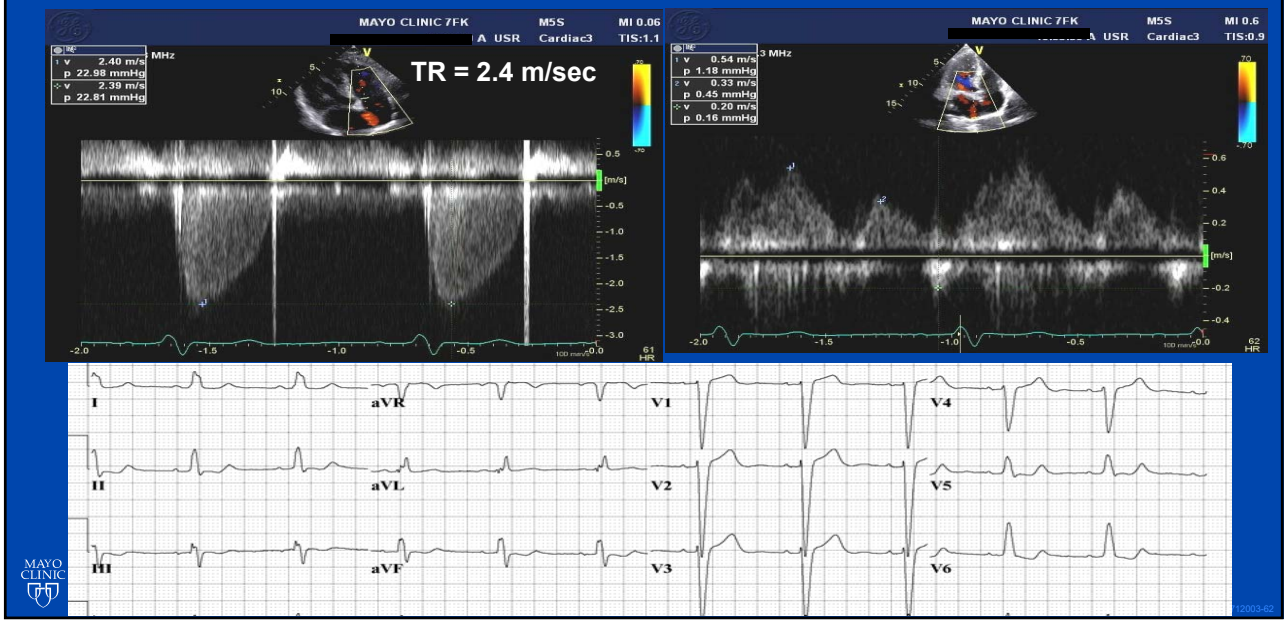
Mitral annulus e' velocity

- ASE/EACVI recommends average value
- E' from one location is acceptable
- We need a caution in using e'
  - Primary pulmonary hypertension
  - Pacemaker
  - LBBB
  - Wall motion abnormality
  - Mitral annulus calcification
  - Hypertrophic CM

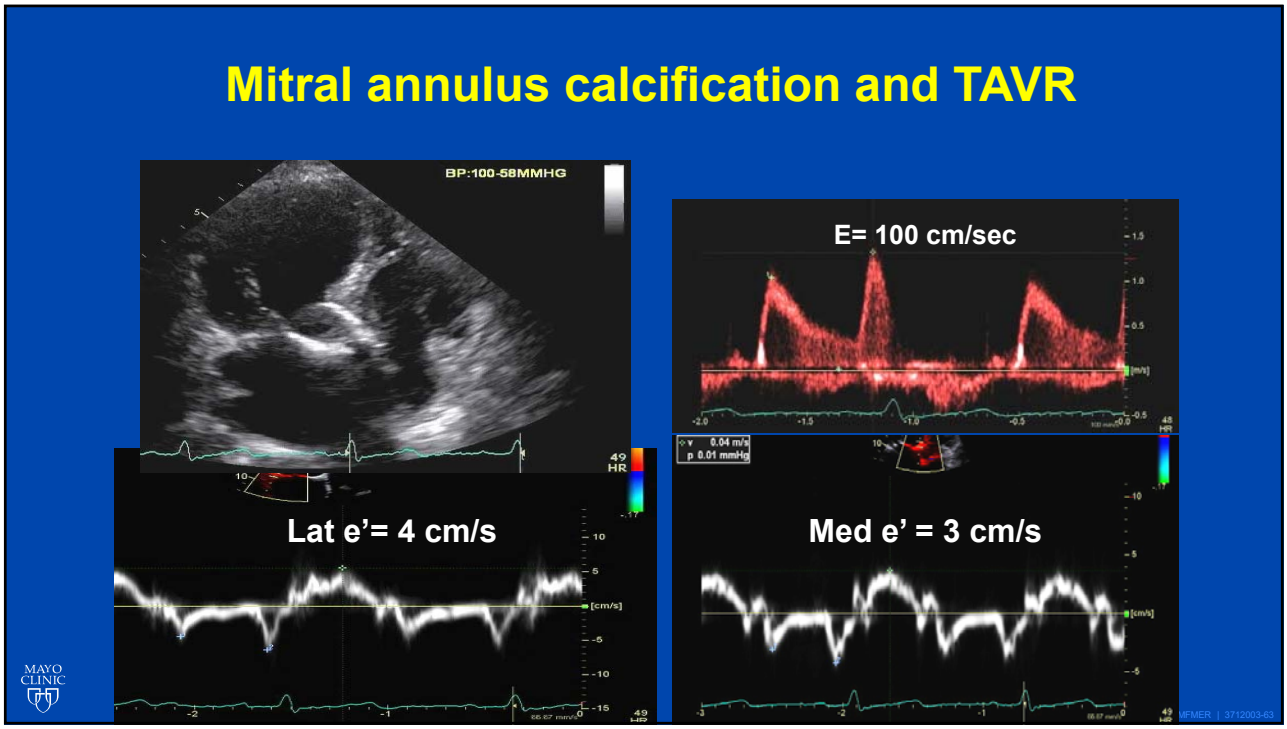
67 yo woman with LBBB



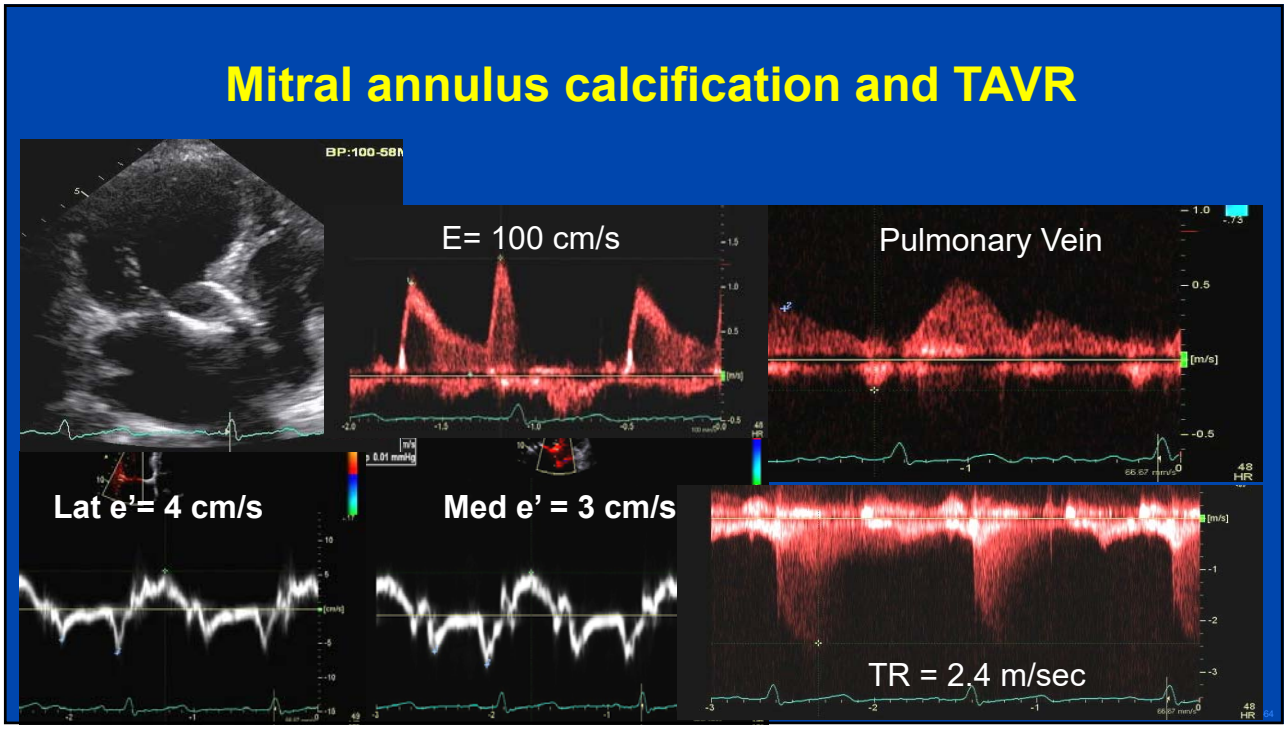
67 yo with LBBB



Mitral annulus calcification and TAVR



Mitral annulus calcification and TAVR



Mitral annulus e' velocity vs MAC
Mean age 73 years

Variable	Group 1 n=79 no MAC	Group 2 n=38 mild MAC	Group 3 n=38 mod-severe MAC	P for trend
Agatston Score	0	1-119	>119	
Septal e'	5.96±1.82	5.15±1.56	5.05±1.93	0.01
Lateral e'	7.37±2.44	6.89±2.71	6.28±1.81	0.01
Average e'	6.63±2	6.02±1.79	5.67±1.69	0.01
E/avg e' ratio	13±4.93	15±8.95	18±8.26	<0.001

LV diastolic parameters are altered in the presence of MAC. This could be due to direct effects of MAC or might reflect truly reduced diastolic function. Interpretation of diastolic parameters in patients with MAC should be performed with caution.

MAYO CLINIC

Codolosa et al: Am J Cardiol 2016;117:847-852

JACC: CARDIOVASCULAR IMAGING
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VOL. ■, NO. ■, 2017
ISSN 1936-878X/$36.00
http://dx.doi.org/10.1016/j.jcmg.2016.10.017

Doppler Echocardiography for the Estimation of LV Filling Pressure in Patients With Mitral Annular Calcification

Muaz M. Abudiab, MD, Lakshmi H. Chebrolu, MD, Robert C. Schutt, MD, Sherif F. Nagueh, MD, William A. Zoghbi, MD

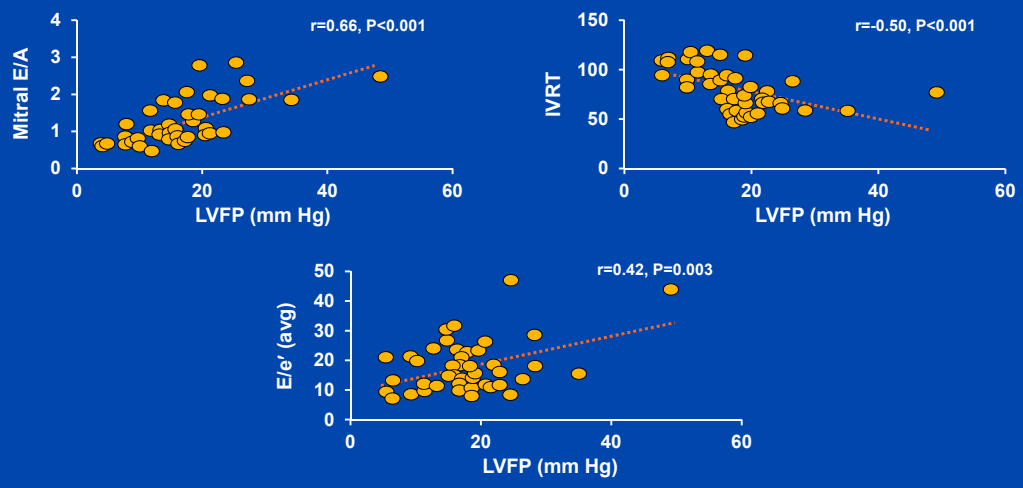
Representative Images of Patients With Mitral Annular Calcification

Mild | Moderate | Severe

MAYO CLINIC

Abudiab et al: Am Coll Cardiol Img, 2017

Correlation of Selected Doppler Variables With Left Ventricular Filling Pressure

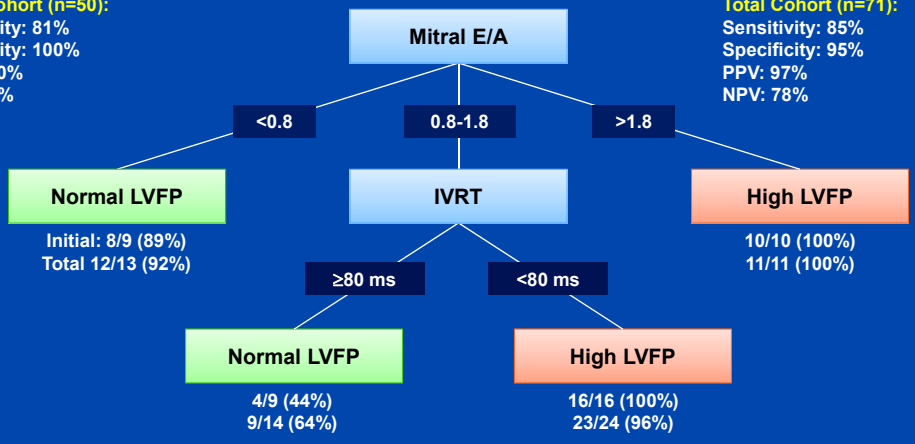


Abudiab et al: Am Coll Cardiol Img, 2017

Proposed Clinical Algorithm for Estimation of Left Ventricular Filling Pressure in Subjects With Mitral Annular Calcification

Initial Cohort (n=50):
Sensitivity: 81%
Specificity: 100%
PPV: 100%
NPV: 67%

Total Cohort (n=71):
Sensitivity: 85%
Specificity: 95%
PPV: 97%
NPV: 78%



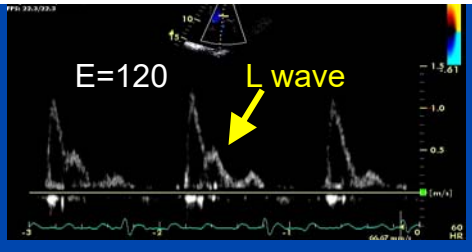
Abudiab et al: Am Coll Cardiol Img, 2017

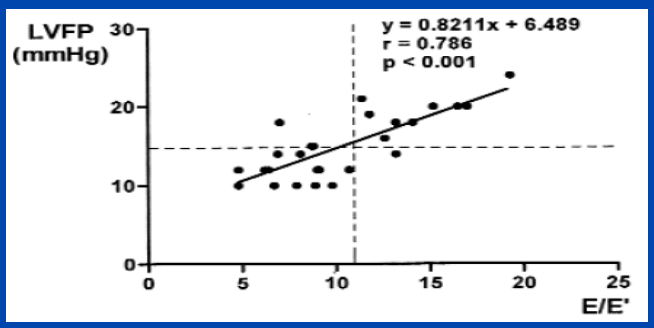
Diastolic Function in A. Fib

- DT < 160 msec (with reduced EF)
- DT < 130 msec poor survival (Hurley, Oh)
- Other measurements
  - E acceleration > 1900 cm/sec^2
  - IVRT ≤ 65 msec
  - E/e' ≥ 11
  - IVRT/ T E-e'
  - TR velocity

Mitral Annulus Velocity in the Evaluation of Left Ventricular Diastolic Function in Atrial Fibrillation

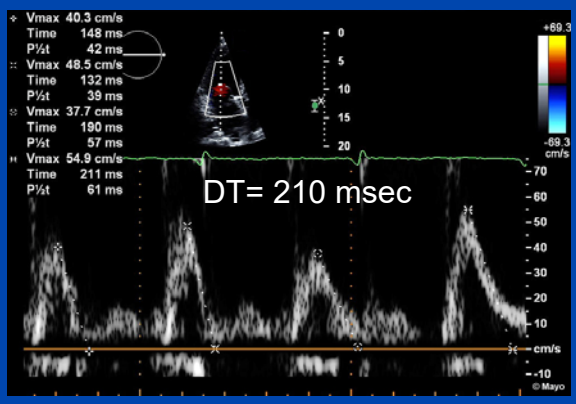
Dae-Won Sohn, MD, Jong-Min Song, MD, Joo-Hee Zo, MD, In-Ho Chai, MD, Hyo-Soo Kim, MD, Hong-Gu Chun, MA, and Hee-Chan Kim, PhD, *Seoul, Korea*

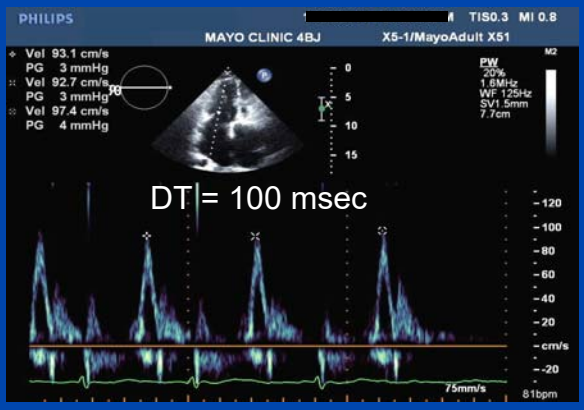




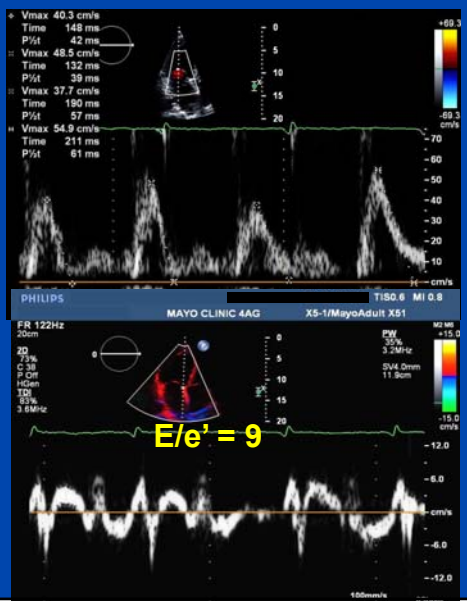
JASE 1999

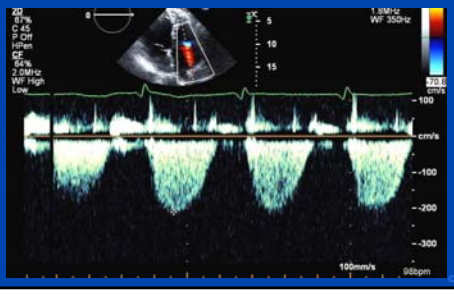
Atrial Fibrillation
Variation in E velocities : NL Pressure



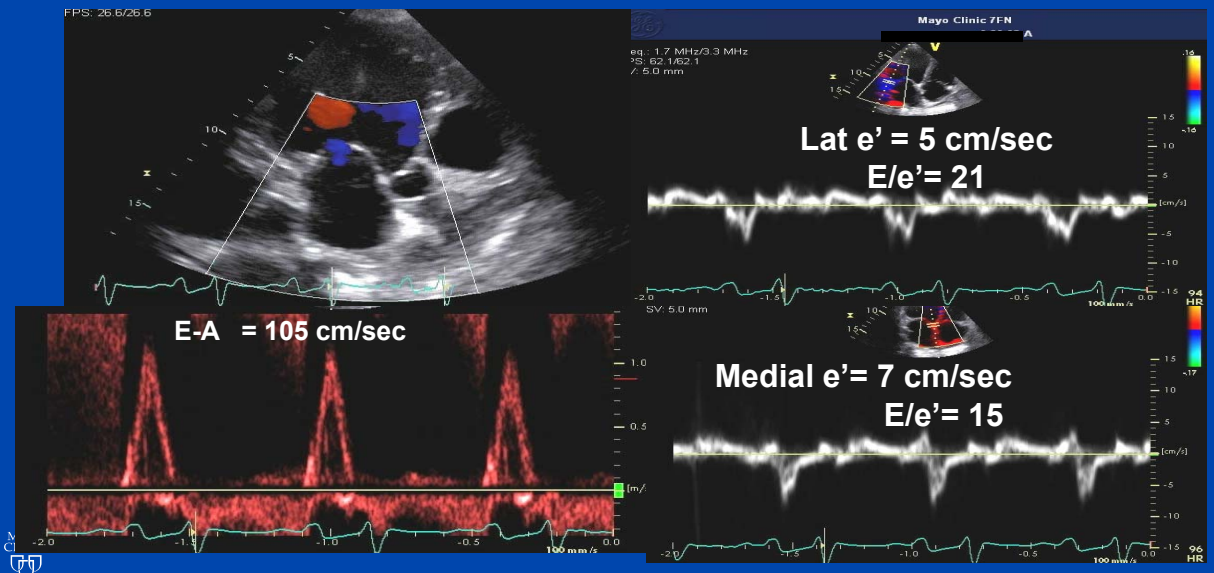


Atrial Fibrillation
Variation in E velocities and E/e' <11

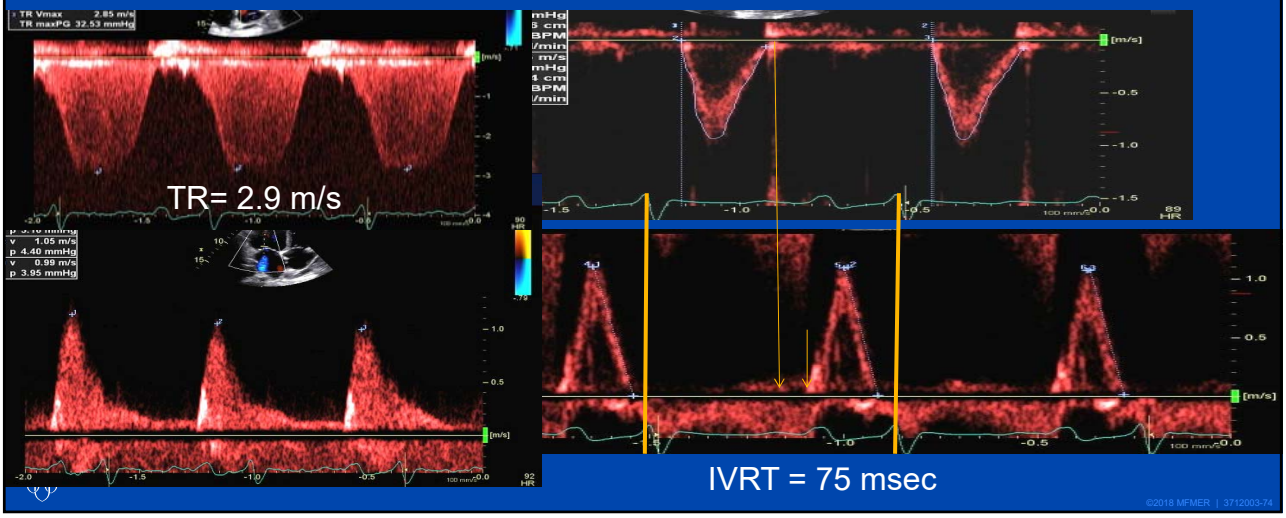




66 yo woman with dyspnea and EF 20%



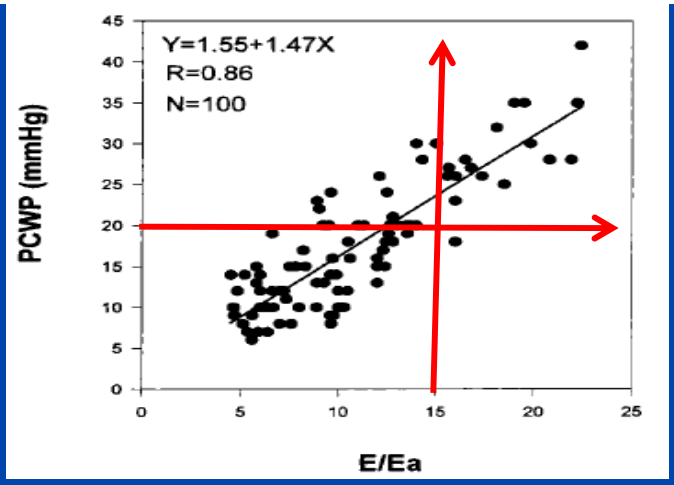
66 yo woman with HF and severe MR
LVEF 20%



Doppler Estimation of Left Ventricular Filling Pressure in Sinus Tachycardia

A New Application of Tissue Doppler Imaging

Sherif F. Nagueh, MD; Issam Mikati, MD; Helen A. Kopelen, RDMS; Katherine J. Middleton, RCT; Miguel A. Quiñones, MD; William A. Zoghbi, MD



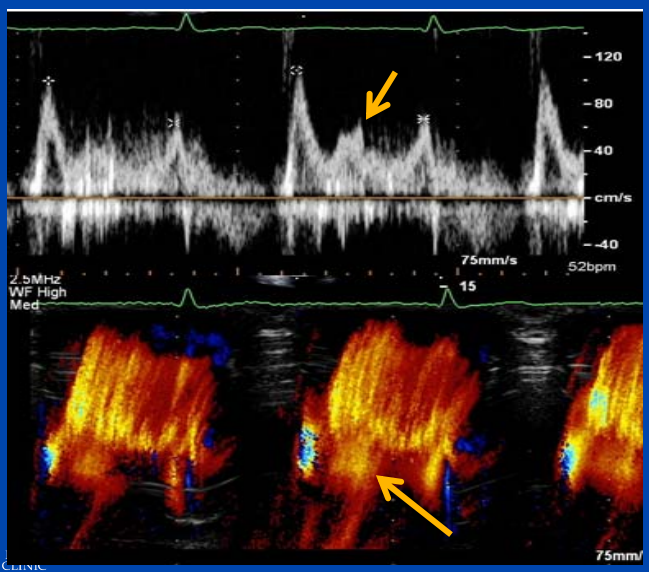
Nagueh et al Circulation 1998

My Recommendations

- For patients with reduced EF (<35%) or with preserved EF with known diastolic dysfunction, evaluate diastolic function based on E/A ratio
- For all other patients, based on the 4 parameters
  - Normal : ≥ 3 normal (for patient's age)
  - Abnormal : ≥ 3 abnormal (grade 2 or 3 based on E/A)
  - Indeterminate : Need help from PV, IVRT, Valsalva, Time interval, Exercise, Strain Imaging

My recommendation based on e' velocity
LV relaxation is the key for normal diastole

- True Normal
  - Medial e' >10 cm/sec or Lateral e' > 15 cm/sec
- Age-related Normal
  - Medial e' 7-10 cm/s or Lateral e' 10-15 with normal TR
- Abnormal
  - Medial e' < 7 cm/s or lateral e'<10 cm/s
  - Grade 1, 2, and 3 based on E/e', TR, and LAVI



Thank you!

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